NATIONAL TECHNICAL UNIVERSITY OF ATHENS
School of Civil Engineering
Department of Water Resources
and Environmental Engineering

Methods and tools supporting operational drought risk management in water stressed areas

PhD Dissertation

Magdalini Kossida

Athens, December 2015

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PREFACE - ACKNOWLEDGEMENTS

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ABSTRACT

Europe has experienced in the past 40 years drought episodes of various severities, duration and extend, with adverse impacts on both the environment and the society. A large scale comparison between the periods 1971-80 and 2001-11 per region (North, Central, Eastern, South EU) clearly shows that drought occurrence has significantly increased in the period 2001-11, not only in the South and Central EU, but also reaching now the North and Eastern EU (Kossida et al., 2012[1]). Drought spells have been further recognized in the River Basin Management Plans, reported by the Member States under the Water Framework Directive (WFD), either as River Basin District wide phenomena or as local phenomena affecting parts of the entire basin in various cases. Policy actions have recently been intensified at the European and national levels in order to effectively implement drought management schemas that can support proactive risk management and consequently increase the resilience and sustainability of the affected regions. The development of such plans requires: (a) the correct identification of the hazard itself, (b) the proper assessment of the underlying vulnerabilities and risk, (c) the identification of robust mitigation measures, (d) the definition of relevant policy targets, and (e) the internalization of the policy targets into development plans and frameworks, and the elaboration of governance schemas, instruments and mechanisms that can support their implementation.

In this direction, the current research **develops a set of operational methods and tools for supporting drought risk management in water stressed areas**. It aims at linking science to the decision and policy-making process, and providing supportive engineering tools. It proposes a holistic methodology based on the basic concepts of mainstreaming (UNDP, 2011[2]) and develops a set of relevant tools for proactive drought risk management and planning, implementing a step-wise approach that integrates physical and anthropogenic drivers and pressures, impacts and response. Mainstreaming is defined as “a process of change, whereby certain issues are integrated into planning and decision-making processes and these issues continue to be part of the

[1] Kossida, M., Kakava, A., Tekidou, A., Iglesias A., Mimikou, M. 2012. Vulnerability to Water Scarcity and Drought in Europe. Thematic assessment for EEA 2012 Report. ETC/ICM Technical Report 2012/3. ISBN 978-80-85087-13-0.

[2] United Nations Development Programme (UNDP), 2011. Mainstreaming Drought Risk Management: A primer. UNDP Publication, March 2011.

agenda in subsequent planning, implementation and revision" (UNDP, 2008[3]). In the context of Drought Risk Management (DRM), mainstreaming clearly relates to proactive risk management, as it helps addressing drought issues not simply as a natural phenomenon but as a more complex development issue. It supports the internalization of drought risk in development framework and sets the cornerstones towards the development of the proper enabling environment and institutional setting. To achieve mainstreaming, and hence proactive risk management, a set of steps must be coherently followed. These steps span from science to policy activities, while interfacing between them holds an important role so that the developed scientific and policy tools are tailored to the local specificities, enhancing the local adaptive capacity.

The current research proposes a generic process for DRM mainstreaming, identifying and building around four basic steps:

- Step 1: Definition and development of a Drought Risk Profile
- Step 2: Identify DRM options: design and simulation of mitigation measures
- Step 3: Prioritize DRM options: Optimization and Decision-making
- Step 4: Internalize DRM: Definition of policy targets and Implementation

Across these four steps, the following tools and methods have been developed:

- A methodology to accurately characterize and map Drought Hazard, based on operational and easily reproducible precipitation-derived indicators, capturing all drought characteristics (frequency, intensity, magnitude, duration, speed of onset). A new drought indicator, the DHI, has been developed hereby.

- A methodology for the characterization and mapping of Drought Vulnerability. A new drought indicator, the DVI, has been developed for this purposes, which is based on the balance between water resources availability and demand (i.e. unmet demand), and thus able to capture socio-economic drivers and pressures. Suggestions on how to obtain estimates of unmet demand are provided, and, the Water Supply and Evaluation tool WEAP21[4] has been assessed as a supporting tool.

- A methodology for developing a Drought Risk Profile (DRP), by overlaying the drought hazard and vulnerability components, and defining relevant thresholds and classes.

[3] United Nations Development Programme (UNDP), 2008. Mainstreaming Drylands Issues into National Development Frameworks: Generic Guidelines and Lessons Leant. Nairobi: UNDP.

[4] Stockholm Environment Institute (SEI), 2015. WEAP Water Evaluation And Planning System. User Guide for WEAP 2015, August 2015.

- A generic methodology for designing Demand Management Options (i.e. interventions and measures covering management, technological and economic aspects) for the urban and agricultural sectors, incorporating the development of "cost-effective intervention curves", able to be adjusted under different regional context and expert input from stakeholders.

- A methodology for linking interventions to the decision-making process. For this purpose a Decision Support System (DSS) linking WEAP21 to MATLAB[5]. The DSS consist of three components: the WEAP21 (i.e. the simulation engine), MATLAB (i.e. the optimization engine), the urban and agricultural intervention curves (i.e. the library of measures), and aims to identify a bundle of optimal mitigation measures for demand management, and assist the policy-making process of targets' definition

- Practical recommendations on internalizing DRM into development framework. For this purpose a methodology for testing the robustness of the optimization results under future climate and socio-economic scenarios (drawing on EU accepted scenarios) has been defined. Practical suggestions and steps on how to define policy-targets, and how to implement a process for integrating them into development framework and plans at different levels (national, regional, local) are also drafted.

The proposed tools are tested and validated in a pilot area in Greece (the Ali-Efenti basin). They have been proven adequate to cover all components which need to be accounted for in proactive drought risk management, supporting the design of medium to longer-term mitigation options (helping thus to remove structural barriers), and enabling the definition of sectoral policy targets and their implementation. They were found adequate to support multiple goals: penetration of measures in local development programmes, development of cross-sectoral and mutually reinforcing policies, creation of an enabling environment and adequate mechanisms for DRM (including decentralized roles). Furthermore, the developed tools are generic, flexible and easily adaptable, expandablea, parsimonious and holistic: they can be modified and adapted to various area-specific contexts, sectoral structures, and technical arrangements; they allow the addition of extra components; their input data are relatively easy to acquire; they have a trans-disciplinary character and integrate environmental (biophysical) with social-economic issues at various spatial scales and within a range of time perspectives.

[5] MATLAB, 2010. Global Optimization Toolbox, User's Guide.

EXTENDED ABSTRACT IN GREEK

ΕΛΛΗΝΙΚΗ ΠΕΡΙΛΗΨΗ ΤΗΣ Δ.Δ.:

"Μέθοδοι και εργαλεία για την υποστήριξη της επιχειρησιακής διαχείρισης του κινδύνου ξηρασίας σε περιοχές με υδατικές πιέσεις"

1. Ερευνητικό υπόβαθρο και Αιτιολόγηση

Τα τελευταία 40 χρόνια η Ευρώπη έχει βιώσει επεισόδια ξηρασίας ποικίλης βαρύτητας, διάρκειας και έκτασης, με αρνητικές επιπτώσεις τόσο στο περιβάλλον όσο και στην κοινωνία. Μία μεγάλης κλίμακας σύγκριση μεταξύ των περιόδων 1971-1980 και 2001-11 ανά περιοχή (Βόρεια, Κεντρική, Ανατολική, Νότια ΕΕ) δείχνει σαφώς ότι τα επεισόδια ξηρασίας έχουν αυξηθεί σημαντικά κατά την περίοδο 2001-11, όχι μόνο στη Νότια και Κεντρική ΕΕ, αλλά και στην Βόρεια και Ανατολική ΕΕ (Κοσσίδα κ.ά., 2012[6]). Φαινόμενα ξηρασίας έχουν περαιτέρω αναγνωριστεί στα Σχέδια Διαχείρισης Λεκανών Απορροής, που έχουν υποβληθεί από τα κράτη-μέλη κατά την εφαρμογή της Οδηγίας Πλαίσιο για τα Νερά (60/2000/ΕΚ), είτε ως ευρύτερα φαινόμενα σε επίπεδο Περιοχής Λεκάνης Απορροής Ποταμού (ΠΛΑΠ) ή ως τοπικά φαινόμενα που επηρεάζουν τμήματα της συνολικής λεκάνης της σε κάποιες περιπτώσεις. Οι δράσεις πολιτικής έχουν πρόσφατα ενταθεί, σε Ευρωπαϊκό και εθνικό επίπεδο, προκειμένου να εφαρμοστούν αποτελεσματικά σχήματα διαχείρισης της ξηρασίας που μπορούν να υποστηρίξουν την προληπτική διαχείριση του κινδύνου και, κατά συνέπεια, την αύξηση της προσαρμοστικότητας και της βιωσιμότητας των πληγεισών περιοχών. Η ανάπτυξη των εν λόγω σχεδίων απαιτεί:

- σωστή αναγνώριση της επικινδυνότητας της φυσικής καταστροφής (ξηρασίας),
- ορθή εκτίμηση της υποκείμενης τρωτότητας και του κινδύνου
- αναγνώριση εύρωστων μέτρων/παρεμβάσεων για το μετριασμό των επιπτώσεων
- ορισμό σχετικών στόχων πολιτικής

[6] Kossida, M., Kakava, A., Tekidou, A., Iglesias A., Mimikou, M. 2012. Vulnerability to Water Scarcity and Drought in Europe. Thematic assessment for EEA 2012 Report. ETC/ICM Technical Report 2012/3. ISBN 978-80-85087-13-0.

- ανάπτυξη διακυβερνητικών σχημάτων που μπορούν να υποστηρίξουν την εφαρμογή τους, βασισμένα σε προηγμένα εργαλεία και θεσμούς («ενσωμάτωση – mainstreaming»)

Στην κατεύθυνση αυτή, η παρούσα έρευνα προτείνει μια σειρά επιχειρησιακών μεθόδων και εργαλείων για την υποστήριξη του έγκαιρου προγραμματισμού και της προληπτικής διαχείρισης του κινδύνου ξηρασίας σε περιοχές με υδατικές πιέσεις.

2. Αντικείμενο και Στόχοι της Διδακτορικής έρευνας

Ο σκοπός της παρούσας έρευνας είναι η **ανάπτυξη επιχειρησιακών μεθόδων και εργαλείων για την υποστήριξη της διαχείρισης του κινδύνου ξηρασίας σε περιοχές με υδατικές πιέσεις.** Η έρευνα στοχεύει στη σύνδεση της επιστήμης με τη διαδικασία λήψης αποφάσεων και χάραξης πολιτικής, και την παροχή υποστηρικτικών εργαλείων μηχανικής. Προτείνει μια ολιστική μέθοδο που στηρίζεται στις βασικές έννοιες της «ενσωμάτωσης – mainstreaming" (UNDP, 2011[7]) και αναπτύσσει μια σειρά σχετικών εργαλείων για την προληπτική διαχείριση και τον σχεδιασμό του κινδύνου ξηρασίας, εφαρμόζοντας μιας σταδιακή προσέγγιση που ενσωματώνει φυσικούς και ανθρωπογενείς παράγοντες και πιέσεις, επιπτώσεις και ανταπόκριση (παρεμβάσεις).
Οι προτεινόμενες μέθοδοι και τα εργαλεία που αναπτύχθηκαν καλύπτουν όλες τις συνιστώσες που πρέπει να ληφθούν υπόψη για τη διαχείριση των κινδύνων ξηρασίας, και εκτείνονται από την αξιολόγηση της επικινδυνότητας της ξηρασίας, στην αξιολόγηση διαθεσιμότητας και ζήτησης των υδάτινων πόρων σε όλους τους οικονομικούς τομείς, στην χαρτογράφηση της τρωτότητας στη λειψυδρία, την ανάπτυξη προφίλ κινδύνου ξηρασίας, και τελικά στο σχεδιασμό των βέλτιστων μέτρων μετριασμού, συνδέοντάς τα με τη διαδικασία λήψης αποφάσεων, προκειμένου να τεθούν στόχοι πολιτικής για την ενσωμάτωση τους σε σχέδια αναπτυξιακού προγραμματισμού.

Για την ολοκλήρωση αυτού του στόχου οι ακόλουθοι επιμέρους στόχοι έχουν επιτευχθεί:

1. Ανάπτυξη μια γενικευμένης διαδικασίας για την «ενσωμάτωση» της Διαχείριση Κινδύνου Ξηρασίας (ΔΚΞ), βασισμένη στις αρχές του UNDP, και καθορισμός των επιμέρους βημάτων, προκειμένου να χρησιμοποιηθεί ως πρότυπο για τους εμπλεκόμενους φορείς.

[7] United Nations Development Programme (UNDP), 2011. Mainstreaming Drought Risk Management: A primer. UNDP Publication, March 2011.

2. Ανάπτυξη μεθοδολογίας για τον ακριβή χαρακτηρισμό και τη χαρτογράφηση της Επικινδυνότητας Ξηρασίας βάση επιχειρησιακών και ευχερώς υπολογιζόμενων δεικτών, βασισμένων σε δεδομένα βροχόπτωσης, οι οποίοι αντικατοπτρίζουν επαρκώς όλα τα χαρακτηριστικά της ξηρασίας (συχνότητα, ένταση, μέγεθος, διάρκεια, δριμύτητα εμφάνισης). Ανάπτυξη ενός νέου Δείκτη Επικινδυνότητας Ξηρασίας (Drought Hazard Index – DHI).
3. Στοιχειοθέτηση σχετικά με τη χρηστικότητα των αναλυτικών Μοντέλων Διαχείρισης Υδατικών Πόρων (ΜΔΥΠ) στον προσδιορισμό των παραμέτρων που συντελούν στην τρωτότητα στη ξηρασία και λειψυδρία. Τα ΜΔΥΠ επιτρέπουν τη λεπτομερή ανάλυση και αξιολόγηση της της κατάστασης και της εξέλιξης των τάσεων του υδατικού ισοζυγίου, καθώς και τη λεπτομερή εικόνα της χρονικής και χωρικής έκτασης του υδατικού ελλείμματος ζήτησης νερού ανά οικονομικό τομέα. Το υδατικό έλλειμμα είναι μια σημαντική παράμετρος για τον καθορισμό της τρωτότητας. Προσδιορισμός των αναγκαίων χαρακτηριστικών και δυνατοτήτων της πλατφόρμας μοντελοποίησης που θεωρείται κατάλληλη προς χρήση σε αυτή τη διαδικασία. Προσδιορισμός των στοιχείων / παραμέτρων του υδρολογικού κύκλου και του υδατικού ισοζυγίου (αποτελέσματα του WRMM), τα οποία αποτελούν σημαντικές συνιστώσες για την εκτίμηση της τρωτότητας (π.χ. αδυναμία κάλυψης της ζήτησης, αξιοπιστία παροχής ύδατος) σε περιοχές με έλλειψη νερού. Επιχειρηματολογία σχετικά με την ικανότητα του λογισμικού WEAP21 να χρησιμοποιηθεί ως περιβάλλον για την ανάπτυξη κατανεμημένων αναλυτικών Μοντέλων Διαχείρισης Υδατικών Πόρων (ΜΔΥΠ), δομημένων με κόμβους, κατάλληλων για τέτοιες εφαρμογές, ακόμα και σε περιοχές με περιορισμένα δεδομένα.
4. Ανάπτυξη ενός αναλυτικού πλαισίου και επιχειρησιακών δεικτών για τον χαρακτηρισμό και τη χαρτογράφηση της τρωτότητας στην ξηρασίας, χρησιμοποιώντας κοινωνικό-οικονομικούς δείκτες που αντικατοπτρίζουν την έκθεση και την ευαισθησία, με βάση τα δεδομένα που τροφοδοτούνται από το ΜΔΥΠ.
5. Ανάπτυξη Προφίλ Κινδύνου Ξηρασίας, με υπέρθεση της επικινδυνότητας και της τρωτότητας στην ξηρασία, και καθορισμός των σχετικών ορίων και κλάσεων.
6. Πρόταση μιας γενικευμένης μεθοδολογία για το σχεδιασμό Μέτρων Διαχείρισης της Ζήτησης (δηλ. παρεμβάσεων που καλύπτουν διαχειριστικές, τεχνολογικές και οικονομικές πτυχές) για τον αστικό και αγροτικό τομέα, ενσωματώνοντας την ανάπτυξη «καμπύλων παρέμβασης – intervention curves» κόστους-οφέλους, οι

οποίες μπορούν να προσαρμοστούν σε διάφορες τοπικές συνθήκες με τη συνδρομή εμπειρογνωμόνων και εμπλεκόμενων φορέων.

7. Έλεγχος/προσομοίωση των επιπτώσεων και της αποτελεσματικότητας των μέτρων διαχείρισης της ζήτησης νερού, έναντι συγκεκριμένων κριτηρίων, με χρήση του λογισμικού WEAP21. Προτάσεις για τον τρόπο ενσωμάτωσης / προσομοίωσης αυτών των μεταβλητών στο λογισμικό WEAP21.
8. Σύνδεση παρεμβάσεων/μέτρων με τη διαδικασία λήψης αποφάσεων: Υποστήριξη λήψης αποφάσεων με την ανάπτυξη ενός Συστήματος Υποστήριξης Αποφάσεων (ΣΥΑ), που συνδέει Μοντέλα Διαχείρισης Υδατικών Πόρων (ΜΔΥΠ) με την εργαλειοθήκη βελτιστοποίησης του Matlab, με σκοπό τον προσδιορισμό των βέλτιστων μέτρων διαχείρισης της ζήτησης. Ανάπτυξη και εφαρμογή ενός αλγορίθμου βελτιστοποίησης με στόχο την επιλογή της βέλτιστης κατανομής των μέτρων σε μια περιοχή μελέτης.
9. Ενσωμάτωση της Διαχείρισης Κινδύνου Ξηρασίας (ΔΚΞ) σε αναπτυξιακά πλαίσια: Έλεγχος αξιοπιστίας / ευρωστίας των αποτελεσμάτων βελτιστοποίησης υπό συνθήκες μελλοντικών κλιματικών και κοινωνικό-οικονομικών σεναρίων (βάση αποδεκτών σεναρίων Ε.Ε.) και προσδιορισμός ενδεικτικών στόχων πολιτικής.
10. Εκτίμηση του μειωμένου κινδύνου ξηρασίας που προκύπτει κατόπιν εφαρμογής της προτεινόμενης πολιτικής/ μέτρων προσαρμογής.
11. Προτάσεις για τον τρόπο εφαρμογής της ΔΚΞ σε δράσεις, προγράμματα ανάπτυξης, πολιτικής, κλπ., και παρακολούθησης των αποτελεσμάτων της ΔΚΞ.
12. Έλεγχος της προτεινόμενης μεθοδολογίας και των εργαλείων σε μια πιλοτική περιοχή στην Ελλάδα, και συγκεκριμένα στη λεκάνη Αλή-Εφέντη, στο βορειοδυτικό τμήμα της Λεκάνης Απορροής Ποταμού (ΛΑΠ) της Θεσσαλίας.

3. Συμβολή της διατριβής στην επιστήμη και Καινοτόμα στοιχεία

Τα κάτωθι πρωτότυπα στοιχεία αναπτύχθηκαν κατά την παρούσα έρευνα:

- Ανάλυση και επέκταση της έννοιας του UNDP «Ενσωμάτωση» της Διαχείρισης Κινδύνου Ξηρασίας (ΔΚΞ) - Mainstreaming Drought Risk Management (DRM)»

- Ανάπτυξη ενός οδικού χάρτη για την ενσωμάτωση της ΔΚΞ, χρήσιμο στους ενδιαφερόμενους φορείς

- Ανάπτυξη και παροχή λειτουργικών μεθόδων και εργαλείων για την ενσωμάτωση της ΔΚΞ.

- Ανάπτυξη του επιχειρησιακού Δείκτη Επικινδυνότητας Ξηρασίας (Drought Hazard Index - DHI) και σχετικής μεθοδολογίας για τον χαρακτηρισμό και την χαρτογράφηση της επικινδυνότητας ξηρασίας

- Ανάπτυξη του Δείκτη Τρωτότητας στην Ξηρασία (Drought Vulnerability Index - DVI) και του μεθοδολογικού πλαισίου ανάλυσης σχετικών κοινωνικο-οικονομικών δεικτών που αντικατοπτρίζουν την έκθεση και την ευαισθησία στις συνθήκες ξηρασίας, προσαρμόσιμο σε διαφορετικές κοινωνικο-οικονομικές συνθήκες.

- Ανάπτυξη μεθοδολογίας για την ανάλυση και χαρτογράφηση Προφίλ Κινδύνου Ξηρασίας (Drought Risk Profiles) με υπέρθεση των προαναφερόμενων συνιστωσών επικινδυνότητας και τρωτότητας.

- Ανάπτυξη μεθοδολογίας για το σχεδιασμό γενικευμένων «καμπύλων παρέμβασης – intervention curves» στον αστικό και αγροτικό τομέα, ενσωματώνοντας μια δέσμη μέτρων διαχείρισης της ζήτησης.

- Διερεύνηση της εισαγωγής εναλλακτικών καλλιεργειών (αλόη βέρα, μπρόκολο, ακτινίδιο) για την υποκατάσταση μέρους των υπαρχόντων, εντατικών σε ανάγκες νερού καλλιεργειών, ως ένα πιθανό μέτρο διαχείρισης της ζήτησης νερού.

- Προτάσεις για τη διαδικασία και τον τρόπο προσομοίωσης/ κωδικοποίησης των παραπάνω «καμπυλών παρέμβασης» (δηλαδή των μέτρων διαχείρισης της ζήτησης) στο λογισμικό WEAP21 μέσω καθορισμένων από το χρήστη παραμέτρων (δημιουργία εντολών κωδικοποίησης στο περιβάλλον WEAP21)

- Δημιουργία μιας Πλατφόρμας Υποστήριξης Αποφάσεων (Decision Support Platform) με διασύνδεση των λογισμικών WEAP21 και Matlab.

4. Συνοπτική επισκόπηση της μεθοδολογικής προσέγγισης

Η «Ενσωμάτωση – Mainstreaming» ορίζεται ως «η διαδικασία αλλαγής, σύμφωνα με την οποία ορισμένα θέματα ενσωματώνονται στο σχεδιασμό και τις διαδικασίες λήψης αποφάσεων, και τα θέματα αυτά εξακολουθούν να αποτελούν μέρος μιας διάταξης στον μελλοντικό σχεδιασμό, την εφαρμογή και την αναθεώρηση αυτής" (UNDP, 2008[8]).

[8] United Nations Development Programme (UNDP), 2008. Mainstreaming Drylands Issues into National Development Frameworks: Generic Guidelines and Lessons Leant. Nairobi: UNDP.

Η «Ενσωμάτωση» βοηθά στην επίτευξη πολλαπλών στόχων, όπως την ανάπτυξη διατομεακών και αλληλοενισχυόμενων πολιτικών, την αξιοποίηση της εθνικής και διεθνούς χρηματοδότησης και άλλων πόρων. Στο πλαίσιο της διαχείρισης του κινδύνου ξηρασίας (Drought Risk Management - DRM), η ενσωμάτωση σχετίζεται σαφώς με την προληπτική διαχείριση του κινδύνου, καθώς βοηθά να αντιμετωπιστεί το πρόβλημα της ξηρασίας όχι απλά ως ένα φυσικό φαινόμενο, αλλά ως ένα πιο σύνθετο ζήτημα σχετιζόμενο με θέματα ανάπτυξης. Υποστηρίζει την εσωτερίκευση του κινδύνου ξηρασίας σε όλες τις φάσεις του σχεδιασμού, της χρηματοδότησης και της υλοποίησης κάθε αναπτυξιακού πλαισίου, και επιπλέον εξασφαλίζει ότι οι τομεακές πολιτικές δεν αλληλοσυγκρούονται όσον αφορά τους επιμέρους στόχους τους μετριασμού και περιορισμού της ξηρασίας (UNDP, 2011[9]). Επιπλέον, θέτει τα θεμέλια για τον προσδιορισμό και την ανάπτυξη ενός κατάλληλου θεσμικού πλαισίου ικανού να ενισχύσει την προσαρμοστική ικανότητα των ευάλωτων κοινοτήτων με σκοπό τη βιώσιμη ανάπτυξη.

Για την επίτευξη της ενσωμάτωσης αυτής, και ως εκ τούτου της προληπτικής διαχείριση των κινδύνων, μια σειρά από βήματα πρέπει να ακολουθούνται με συνέπεια. Τα βήματα αυτά εκτείνονται από επιστημονικές σε πολιτικές δράσεις, ενώ η διασύνδεση μεταξύ αυτών κατέχει σημαντικό ρόλο, έτσι ώστε τα επιστημονικά εργαλεία που αναπτύσσονται και τα εργαλεία πολιτικής να είναι προσαρμοσμένα στις τοπικές ιδιαιτερότητες και να μπορούν άμεσα να στηρίξουν τις μελλοντικές εξελίξεις ενίσχύοντας της τοπική προσαρμοστική ικανότητα. Η μεθοδολογία που αναπτύχθηκε στο πλαίσιο της παρούσας έρευνας προσδιορίζει και αναπτύσσεται γύρω από τέσσερα βασικά βήματα, ενώ για κάθε βήμα παρέχονται σύνθετες μέθοδοι και εργαλεία για την υποστήριξη της υλοποίησής τους σε επιχειρησιακή κλίμακα. Επισημαίνεται ότι η κυρίαρχη καινοτομία της υφιστάμενης μεθοδολογίας δεν είναι μόνο ότι προτείνει μια σειρά από βήματα για την προληπτική διαχείριση του κινδύνου ξηρασίας, αλλά αναπτύσσει μεθόδους και εργαλεία που μπορούν να υποστηρίξουν την πραγματική επιχειρησιακή εφαρμογή αυτών των βημάτων, και τα οποία είναι προσαρμόσιμα σε διαφορετικές συνθήκες. Τα προτεινόμενα εργαλεία (για τα 4 στάδια) καλύπτουν όλες τις συνιστώσες που πρέπει να ληφθούν υπόψη για τη

[9] United Nations Development Programme (UNDP), 2011. Mainstreaming Drought Risk Management: A primer. UNDP Publication, March 2011.

διαχείριση του κινδύνου ξηρασίας, και εκτείνονται από την αξιολόγηση της επικινδυνότητας της ξηρασίας, στην αξιολόγηση της διαθεσιμότητας των υδατικών πόρων και της ζήτησης νερού από τους οικονομικούς τομείς, στη χαρτογράφηση της τρωτότητας στη λειψυδρία και την ανάπτυξη προφίλ κινδύνου ξηρασίας, και τελικά οδηγούν στο σχεδιασμό των βέλτιστων μέτρων μετριασμού, συνδέοντάς τα με τη διαδικασία λήψης αποφάσεων προκειμένου να θέσουν στόχους πολιτικής, για την εσωτερίκευση τους σε πλαίσια αναπτυξιακού προγραμματισμού.

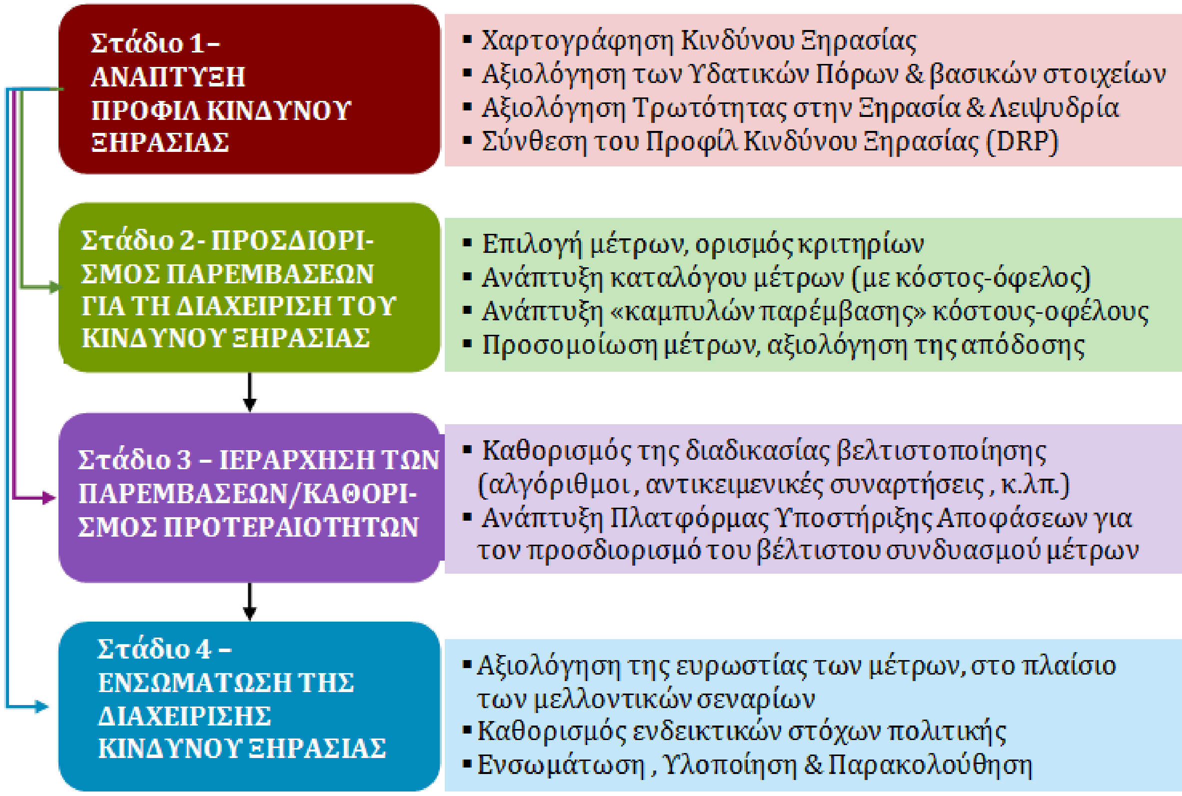
Τα τέσσερα προτεινόμενα βήματα (που πρέπει να ακολουθούνται κατά σειρά) για την προληπτική διαχείριση του κινδύνου ξηρασία που αναπτύχθηκαν στην παρούσα έρευνα, παρουσιάζονται παρακάτω (Εικόνα 1) και έχουν εναρμονιστεί (σε μεγάλο βαθμό) με το προτεινόμενα βήματα της ενσωμάτωση της ΔΚΞ του UNDP.

Στάδιο 1: Ορισμός και ανάπτυξη Προφίλ Κινδύνου Ξηρασίας

Στάδιο 2: Προσδιορισμός παρεμβάσεων για τη ΔΚΞ: σχεδιασμό και προσομοίωση των μέτρων μετριασμού

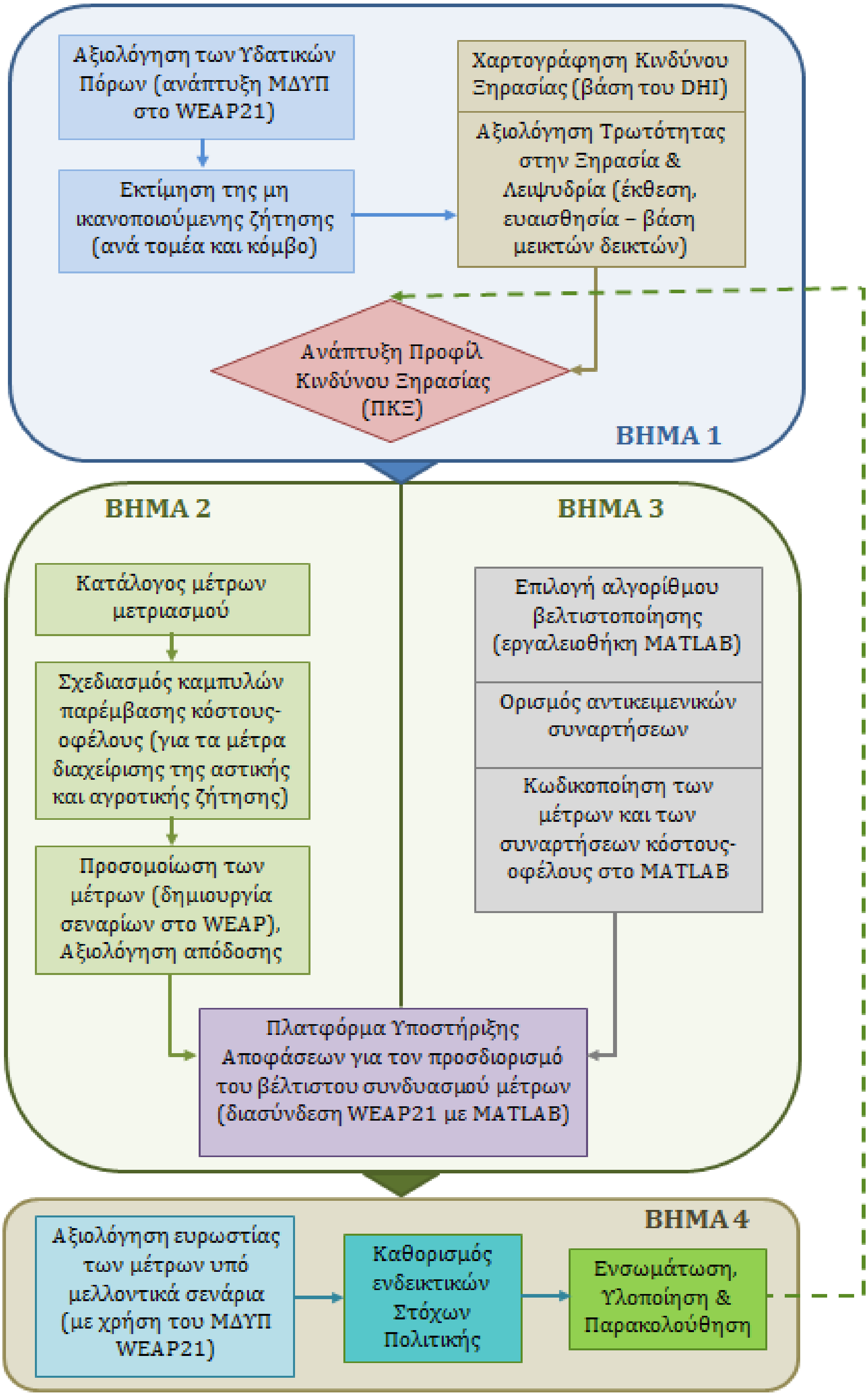
Στάδιο 3: Ιεράρχηση των παρεμβάσεων και καθορισμός προτεραιοτήτων: Βελτιστοποίηση και λήψη αποφάσεων

Στάδιο 4: Ενσωμάτωση της ΔΚΞ: Ορισμός των στόχων πολιτικής και εφαρμογή



Σχήμα 1: Κύρια στάδια και δράσεις για την ενσωμάτωση της Διαχείρισης του Κινδύνου Ξηρασίας

Για την υλοποίηση των τεσσάρων προτεινόμενων βημάτων αναπτύχθηκε ένα σύνολο εργαλείων. Οι λεπτομέρειες του κάθε βήματος, και τα προτεινόμενα εργαλεία που υποστηρίζουν την εφαρμογή τους αναπτύχθηκαν στην παρούσα έρευνα, και δοκιμάστηκαν πιλοτικά στη διαχειριστική λεκάνη του Αλή-Εφέντη στην Ελλάδα. Στο Σχήμα 2 παρουσιάζεται η επισκόπηση της μεθοδολογίας και οι διασυνδέσεις μεταξύ των βημάτων και των υποστηρικτικών εργαλείων και μεθοδολογιών.



Σχήμα 2: Συνοπτική επισκόπηση της μεθοδολογικής προσέγγισης: βήματα και σχετιζόμενες μέθοδοι και εργαλεία.

5. Δομή της Διδακτορικής Διατριβής

Η Διδακτορική Διατριβή είναι δομημένη γύρω από 9 κεφάλαια. Μια επισκόπηση των κεφαλαίων και σύντομη περιγραφή τους παρουσιάζονται ακολούθως.

- **Κεφάλαιο 1 : Εισαγωγή**

Το κεφάλαιο αυτό παρέχει μια εισαγωγή και ορίζει το σχετικό πλαίσιο της παρούσας διατριβής. Παρουσιάζεται το φυσικό και πολιτικό πλαίσιο/ πεδίο εφαρμογής οι ειδικούς στόχους της έρευνας , η συμβολής της διδακτορικής έρευνας στην επιστήμη και τα καινοτόμα στοιχεία.

- **Κεφάλαιο 2 : Ευρωπαϊκή Πολιτική σε σχέση με την Ξηρασία**

Αυτό το κεφάλαιο παρουσιάζει την Ευρωπαϊκή Πολιτική για τη λειψυδρία και την ξηρασία. Αναλύονται οι ελλείψεις της Οδηγίας Πλαίσιο για τα Νερά (ΕΚ/2000/60) όσον αφορά την αντιμετώπιση των προβλημάτων ξηρασίας, καθώς και ο λεπτομερής οδικός χάρτης των δραστηριοτήτων και πρωτοβουλιών της Ε.Ε., σε επίπεδο πολιτικής, σε σχέση με τη λειψυδρία και την ξηρασία. Τέλος, αναλύονται οι ειδικοί στόχοι της Ανακοίνωσης της Ευρωπαϊκής Επιτροπής του 2007 για τη λειψυδρία και την ξηρασία παρουσιάζεται, και η πρόοδος που έχει επιτευχθεί σε σχέση με αυτούς τους στόχους.

- **Κεφάλαιο 3 : Μεθοδολογική Προσέγγιση**

Το κεφάλαιο αυτό εξετάζει τη συνολική μεθοδολογία που αναπτύχθηκε στο πλαίσιο της παρούσας έρευνας για την «ενσωμάτωση» της Διαχείριση Κινδύνου Ξηρασίας (ΔΚΞ) . Ξεκινώντας με την παρουσίαση των βασικών εννοιών της ΔΚΞ και των σημερινών προκλήσεων και των κενών (βιβλιογραφική ανασκόπηση) , το κεφάλαιο αυτό παρουσιάζει μια επισκόπηση της μεθοδολογικής προσέγγισης, αρθρώνοντας τα διάφορα στάδια και τις αμοιβαίες σχέσεις τους . Περισσότερες λεπτομέρειες για τη μεθοδολογία του κάθε βήματος που προβλέπεται παρατίθενται στα επόμενα κεφάλαια 4-7.

- **Κεφάλαιο 4: Ορισμός και ανάπτυξη Προφίλ Κινδύνου Ξηρασίας (Drought Risk Profile - DRP)**

Αυτό το κεφάλαιο πραγματεύεται την ανάπτυξη ενός αναλυτικού πλαισίου για το χαρακτηρισμό και τη χαρτογράφηση του κινδύνου ξηρασίας. Παρουσιάζει τα βήματα, και τη σχετική μεθοδολογία για την ανάπτυξη του ΠΚΞ, το οποίο βασίζεται: (α) στην ανάλυση και χαρτογράφηση της επικινδυνότητας ξηρασίας, (β) στην αξιολόγηση της διαθεσιμότητας των υδατικών πόρων και της ζήτησης νερού (δηλαδή του υδατικού ισοζυγίου) σε αναλυτική κατανεμημένη χωρική και χρονική κλίμακα, (γ) στην ενσωμάτωση κοινωνικο-οικονομικών παραμέτρων για τον τελικό καθορισμό της τρωτότητας και του κινδύνου ξηρασίας και λειψυδρίας.

Η προτεινόμενη μεθοδολογία για την ανάπτυξη των ΠΚΞ έχει δοκιμαστεί στην πιλοτική περιοχή Αλή Αφέντη. Η μεθοδολογία είναι γενικευμένη και μπορεί να επεκταθεί σε περιοχές που πλήττονται από την ξηρασία. Βασίζεται στη χρήση επιχειρησιακών δεικτών που αντικατοπτρίζουν επαρκώς όλα τα χαρακτηριστικά της ξηρασίας (συχνότητα, μέγεθος ένταση/ δριμύτητα, διάρκεια) και ενσωματώνουν περαιτέρω κοινωνικο-οικονομικές συνιστώσες (υπολογισμένες μέσω κατάλληλων προσεγγίσεων) προκειμένου να αξιολογήσουν τη σχετική τρωτότητα και τον κίνδυνο.

Η σωστή αποτίμηση της ισορροπίας μεταξύ της διαθεσιμότητας και της ζήτησης υδατικών πόρων (ελλείμματος ή πλεονάσματος) θεωρείται ως σημαντική συνιστώσα στην παραπάνω διαδικασία ενσωμάτωσης, καθώς βρίσκεται στο επίκεντρο κάθε σχεδίου αξιολόγησης και διαχείρισης της ξηρασίας. Η συχνή έλλειψη δεδομένων (ανά τομέα και χρήστη) συχνά αποτρέπει τον ακριβή υπολογισμό αυτής της παραμέτρου/ δείκτη, και συνεπάγεται την αναγκαιότητα ανάπτυξης κατάλληλων μοντέλων, ικανών να αποτιμούν τη διαθεσιμότητα των υδατικών πόρων στο χρόνο και στο χώρο. Η ακριβής αναπαράσταση και προσομοίωση όλων των φυσικών και ανθρωπογενών χαρακτηριστικών είναι δύσκολη και απαιτεί ευελιξία και προσαρμοστικότητα των εργαλείων μοντελοποίησης. Η ικανότητα του WEAP21 ως σύγχρονο εργαλείο, ικανό να υποστηρίξει τέτοιες εφαρμογές μοντελοποίησης σε περιπτώσεις με περιορισμένα πρωτογενή δεδομένα, συζητείται σε αυτό το κεφάλαιο. Επιπλέον, η επιλογή του WEAP21 ως κεντρική συνιστώσα του Συστήματος Υποστήριξης Αποφάσεων δικαιολογείται με την παράθεση των δυνατοτήτων που προσφέρει στο πλαίσιο αυτό (π.χ. λειτουργία ανάπτυξης σεναρίων, δυνατότητες προσθήκης παραμέτρων καθορισμένες από το χρήστη, API, κλπ.).

- **Κεφάλαιο 5: Σχεδιασμός και προσομοίωση των μέτρων άμβλυνσης**

Αυτό το κεφάλαιο διερευνά την επίδρασης της «Πολιτικής Διαχείρισης της Ζήτησης», συμπεριλαμβανομένης της αλλαγής της χρήσης γης, με βάση μια δέσμη των τεχνολογικών και διαχειριστικών μέτρων που προωθούν την εξοικονόμηση νερού και τη βελτίωση της αποτελεσματικότητας χρήσης του νερού στον αστικό και αγροτικό τομέα. Η μεθοδολογία για το σχεδιασμό γενικευμένων "καμπυλών παρεμβάσεων – intervention curves» (ενσωματώνοντας μια δέσμη μέτρων διαχείρισης της ζήτησης) στον αστικό και αγροτικό τομέα παρουσιάζεται αναλυτικά. Οι «καμπύλες παρεμβάσεων» προσομοιώνουν τα πιθανά οφέλη (από άποψη εξοικονόμησης νερού) και το κόστος των επιλεγμένων μέτρων ως αποτέλεσμα μιας διαδικασίας βελτιστοποίησης. Στο κεφάλαιο παρουσιάζεται επίσης η σύνδεση των καμπυλών στο λογισμικό WEAP21 και διευκρινίζονται οι τρόποι προσομοίωσής τους μέσω παραμέτρων (ορισμένων από το χρήστη) στο WEAP21. Τα επιλεγμένα μέτρα έχουν προσομοιωθεί στη λεκάνη του Αλή-Αφέντη προκειμένου να αξιολογηθούν οι επιπτώσεις τους στην πιλοτική περιοχή (με τη χρήση του ΜΔΥΠ).

- **Κεφάλαιο 6 : Ιεράρχηση των παρεμβάσεων μετριασμού ξηρασίας: Βελτιστοποίηση και λήψη αποφάσεων**

Το κεφάλαιο αναλύει τις βασικές συνιστώσες της προτεινόμενης Πλατφόρμας Υποστήριξης Αποφάσεων (Decision Support Platform - DSP) που θα χρησιμοποιηθεί για τον μετριασμό του κινδύνου ξηρασίας, υποστηρίζοντας τη λήψη αποφάσεων και τον καθορισμό στόχων πολιτικής. Παρουσιάζεται η σύνδεση του εργαλείου βελτιστοποίησης του MATLAB με το περιβάλλον του WEAP21, προκειμένου να βρεθεί η βέλτιστη επιλογή μέτρων διαχείρισης της ζήτησης στον αστικό και αγροτικό τομέα συνδυαστικά. Αυτό το εργαλείο επιτρέπει στους ενδιαφερόμενους να σχεδιάζουν μέτρα και στόχους πολιτικής μέσω προτιμήσεων και περιορισμών που θέτουν (π.χ. διαθέσιμο κόστος επένδυση, διάρκεια ζωής των παρεμβάσεων, δυνατότητα ενσωμάτωσης/αποδοχής των μέτρων, κλπ.). Η μεθοδολογία δοκιμάστηκε στη λεκάνη του Αλή-Εφέντη.

- **Κεφάλαιο 7: Ενσωμάτωση της ΔΚΞ: Ορισμός των στόχων πολιτικής και εφαρμογή**

Αυτό το κεφάλαιο παρουσιάζει επιλογές για τον έλεγχο της αξιοπιστίας και ευρωστίας των επιλεγμένων λύσεων (από το προηγούμενο κεφάλαιο) με βάση μελλοντικά κλιματικά και κοινωνικο-οικονομικά σενάρια. Με βάση την ευρωστία των αποτελεσμάτων, ορίζονται στόχοι πολιτικής, και ακολουθείται μια διαδικασία διερεύνησης των δυνατοτήτων ενσωμάτωσης των αξόνων της ΔΚΞ στο εθνικό πλαίσιο ανάπτυξης, την εθνική και την περιφερειακή πολιτική και τις τομεακές στρατηγικές. Συζητούνται διάφορα πλαίσια, καθώς και μέσα για την παρακολούθηση των επιπτώσεων της ενσωμάτωσης της ΔΚΞ (είτε από την άποψη των αλλαγών στην προσαρμοστική ικανότητα ή στην ανάπτυξη πολιτικής διαδικασίας).

- **Κεφάλαιο 8: Έλεγχος της μεθοδολογίας στην πιλοτική λεκάνη απορροής του Αλή-Εφέντη**

Το κεφάλαιο αυτό παρουσιάζει τον έλεγχο της μεθοδολογίας που αναπτύχθηκε σε μια πιλοτική περιοχή στην Κεντρική Ελλάδα, και συγκεκριμένα την υδρολογική λεκάνη Αλή-Εφέντη, της Λεκάνης Απορροής Ποταμού (ΛΑΠ Πηνειού). Όλα τα βήματα της μεθοδολογίας (όπως παρουσιάζονται στα προηγούμενα κεφάλαια 3-7), συμπεριλαμβανομένης της ανάπτυξης ενός Μοντέλου Διαχείριση Υδάτινων Πόρων (ΜΔΥΠ) για τη λεκάνη απορροής του Αλή-Εφέντη , έχουν εφαρμοστεί στο κεφάλαιο αυτό, προκειμένου να ελεγχθεί η αξιοπιστία της μεθοδολογίας σε ένα φυσικό σύστημα. Τα αποτελέσματα και τα συμπεράσματα για τη λεκάνη απορροής του Αλή-Εφέντη παρουσιάζονται και συζητούνται αναλυτικά.

- **Κεφάλαιο 9: Συμπεράσματα και Συστάσεις**

Αυτό το κεφάλαιο ενοποιεί τα κύρια αποτελέσματα και τα συμπεράσματα της έρευνας από όλα τα μεθοδολογικά βήματα. Συζητείται η αξία των προτεινόμενων μεθόδων και εργαλείων στις διαδικασίες λήψης αποφάσεων με στόχο το μετριασμό του κινδύνου ξηρασίας και λειψυδρίας, και την υιοθέτηση μιας προληπτικής προσέγγισης. Τέλος, αναφέρεται σε θέματα χάραξης πολιτικής, παρουσιάζοντας πιθανές προσεγγίσεις ένταξης των εργαλείων που αναπτύχθηκαν στην αλυσίδα της διαδικασίας χάραξης πολιτικής.

CHAPTER 1 – INTRODUCTION

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1 INTRODUCTION

1.1 The overall framing context

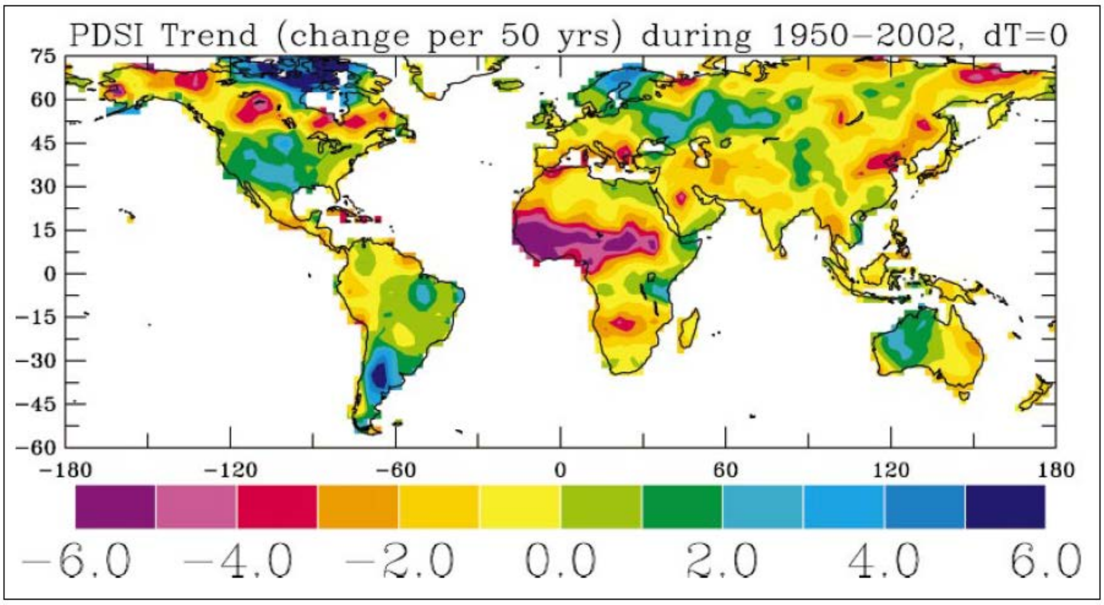
1.1.1 The physical context: increasing drought trends

Drought is defined as a temporary deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people (NOAA National Weather Service, 2008). Drought is different than aridity, where low precipitation is a permanent characteristic of the climate of a certain region. Multiple conceptual and operational definitions are used worldwide, differentiating drought on the basis on its impacts, scale of operation, etc. (Box 1.1)

Box 1.1: Common drought definitions

Drought definitions
Meteorological drought is usually defined based on the degree of dryness (in comparison to some "normal" or average) and the duration of the dry period. Drought onset generally occurs with a meteorological drought.
Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, soil water deficits, reduced ground water or reservoir levels needed for irrigation.
Hydrological drought usually occurs following periods of extended precipitation shortfalls that impact water supply (i.e., streamflow, reservoir and lake levels, ground water), potentially resulting in significant societal impacts.
Source: NOAA National Weather Service, 2008. Drought public factsheet, May 2008. Available online at: http://www.nws.noaa.gov/os/brochures/climate/DroughtPublic2.pdf

It has become apparent that although drought is a normal, recurrent feature of climate, drought episodes are becoming more and more frequent and severe worldwide. During the last millennium there is high confidence that droughts of greater magnitude and longer duration than those observed since the beginning of the 20th century have occurred in many regions (IPCC 2013, pp.50). Dai et. al., 2004, analyzed drought trends based on a monthly global dataset of Palmer Drought Severity Index (PDSI) from 1870–2002, using historical precipitation and temperature data on a 2.5° grid. The results suggest that the very dry areas globally (with a PDSI < −3.0) have more than doubled since the 1970s, with a large jump occurring in the early 1980s due to an ENSO (El Niño Southern Oscillation) induced precipitation decrease and surface warming, while global very wet areas (PDSI > +3.0) declined slightly during the 1980s. These results provide observational evidence for the increasing risk of droughts as global warming progresses and produces increased temperatures and drying.



Map 1.1: Map of linear trends of PDSI [change (50 yr)$^{-1}$, calculated with both precipitation and temperature changes] during 1950–2002.
Red and blue areas indicate drying and wetting respectively. Source: Dai et. al., 2004.

An overview analysis of the evolution of main drought disasters across the globe is presented in Figure 1.1-Figure 1.3 below. The data used in this analysis have been retrieved from the EM-DAT International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED). EM-DAT contains basic information (occurrence, population affected, economic losses, mortalities, etc.) on the main disasters (natural and technological) including drought. In this analysis the countries have been grouped under 5 main regions (Africa, Asia, Americas, Europe, Oceania) and 15-year periods have been aggregated from 1955-2014. It is clearly demonstrated that the main drought disasters increase in occurrence (more countries affected) between 1955-1969 and 2000-2014 across all 5 regions. African countries are overall mostly affected, followed by Asian, the Americas, Europe and Oceania. In terms of total population affected and total economic damage cost, increasing trends are observed again in the most recent periods. The most affected region in terms of population is by far Asia, while the Americas have suffered the greatest economic damage especially in the period 2000-2014 (followed by Asia and Europe). The reported numbers raise concern: from roughly 150 countries affected during the mid-80's, up to 250 are affected in the recent 2000-2014 period, and with the total population affected doubling-up (now reaching 900,000,000 people as compared to 450,000,000). The total economic damage of the last 15 years (across all regions) is about 72 billion US dollars as opposed to 17 in the mid-1980s'. The top-10 most important drought disasters for the period 1900 to 2015 sorted by economic damage costs at the country level are presented in Table 1.1 below. It is observed that 6 out of the 10 most important drought disasters globally have occurred in last 15-year period, after 2000.

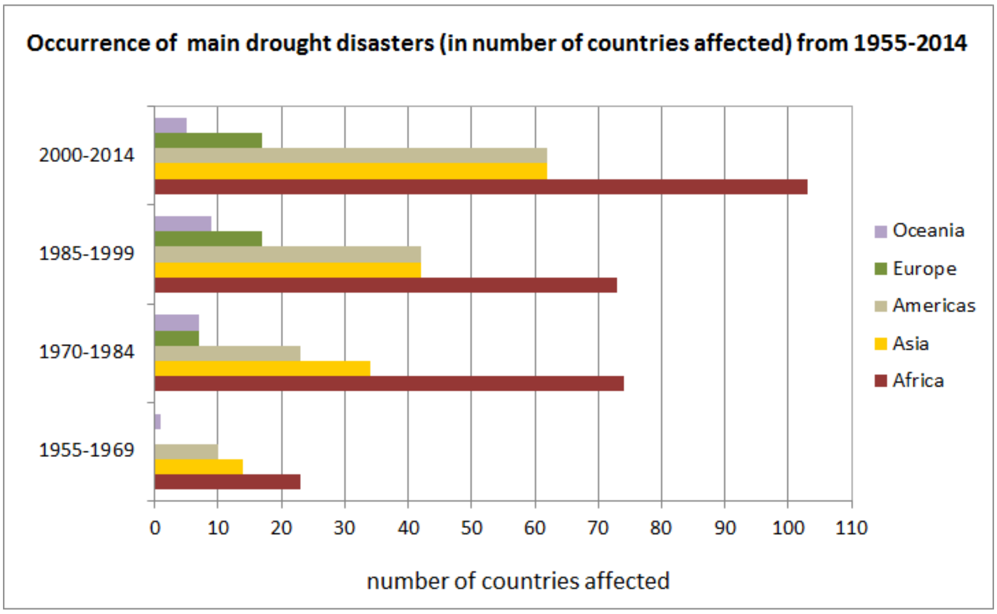


Figure 1.1: Occurrence of main drought disasters (in number of countries affected) from 1955-2014. Data source: EM-DAT International Disaster Database**Error! Bookmark not defined.**.

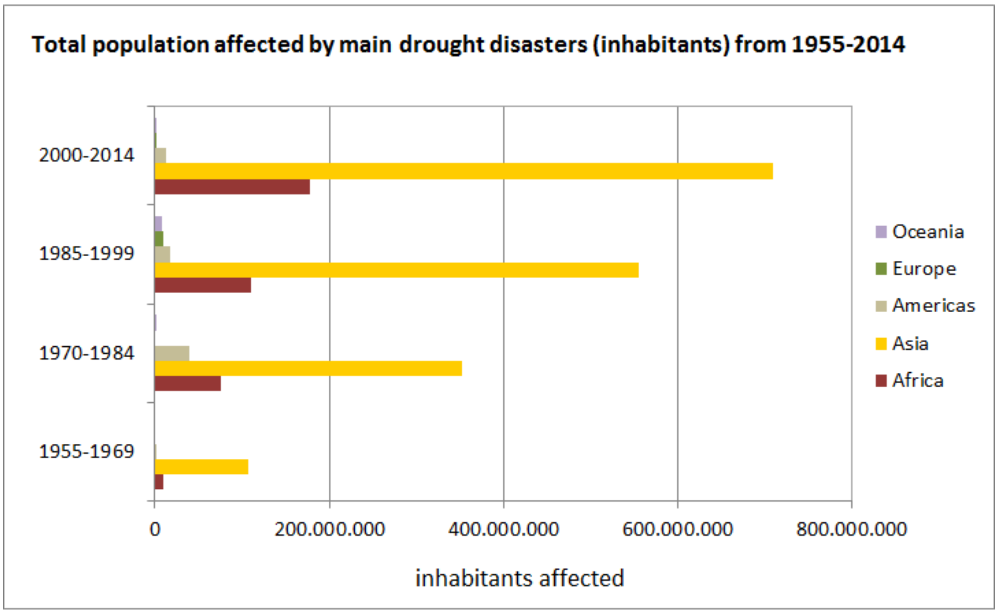


Figure 1.2: Total population affected by main drought disasters (inhabitants) from 1955-2014. Data source: EM-DAT International Disaster Database**Error! Bookmark not defined.**.

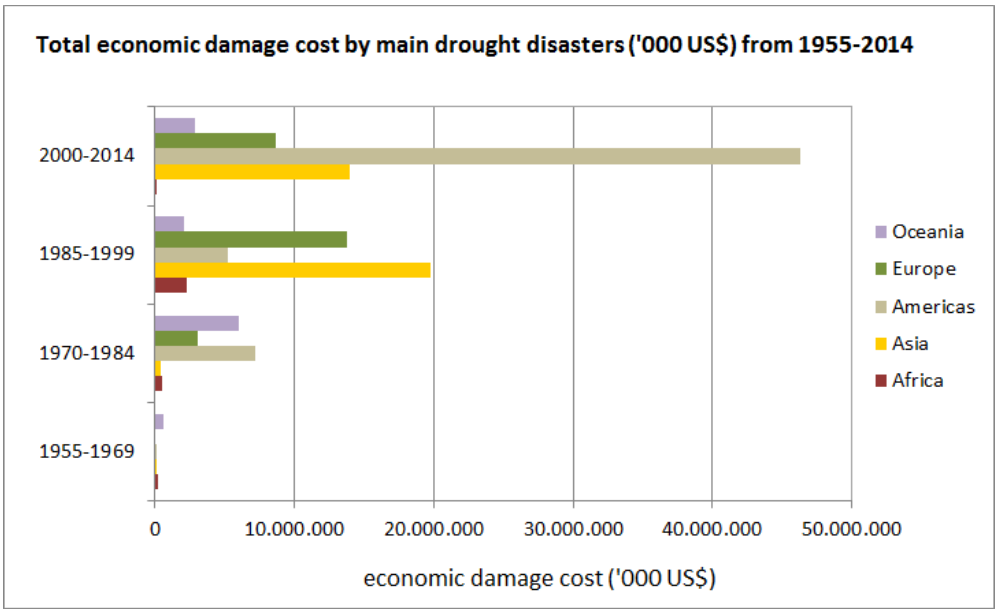


Figure 1.3: Total economic damage cost by main drought disasters ('000 US$) from 1955-2014. Data source: EM-DAT International Disaster Database**Error! Bookmark not defined.**.

Table 1.1: The top-10 most important drought disasters for the period 1900 to 2015 at the country level, sorted by economic damage costs.

Country	Date	Economic Damage (in US $)
United States	June 2012	$ 20,000,000,000 $
China P. Rep.	January 1994	13,755,200,000 $
United States	January 2011	8,000,000,000 $
Australia	1981	6,000,000,000 $
Spain	September 1990	4,500,000,000 $

Brazil	January 2014	4,300,000,000 $
United States	January 2014	4,000,000,000 $
China P. Rep.	October 2009	3,600,000,000 $
Iran Islam Rep.	April 1999	3,300,000,000 $
United States	July 2002	3,300,000,000 $

Created on: 29/01/2015. Source: EM-DAT International Disaster Database**Error! Bookmark not defined.**, Data version: v12.07.

The increasing risks of drought and water scarcity have been recognized at the higher political level by various agencies and international stakeholders. In 2013, during the World Day to Combat Desertification and Drought, the Secretary-General of the United Nations, Ban Ki-moon, stated[1]: "*With the rallying call 'Don't let our future dry up', this year's World Day to Combat Desertification is dedicated to highlighting the global risks of drought and water scarcity. Over the past quarter-century, the world has become more drought-prone, and droughts are projected to become more widespread, intense and frequent as a result of climate change. The long-term impacts of prolonged drought on ecosystems are profound, accelerating land degradation and desertification. The consequences include impoverishment and the risk of local conflict over water resources* and productive land". During the opening session of the High-level Meeting on National Drought Policy (HMNDP) on March 2013, the Secretary-General of the World Meteorological Organization, Michel Jarraud, stated[2]: *"The frequency, intensity, and duration of droughts are expected to rise in several parts of the world as a result of climate change, with an increasing human and economic toll. We simply cannot afford to continue in a piecemeal, crisis-driven mode*". Along the same lines, the Food and Agriculture Organization of the United Nations (FAO) Land and Water Division (NRL) reports that since 1900 more than 11 million people have died as a consequence of drought and more than 2 billion have been affected by drought (larger than any other physical hazard) (FAO NRL, 2012). While regional droughts have occurred in the past, their spatial extent is now widespread and consistent with expected changes in the hydrologic cycle under warming. All continents have been affected, and the most recent impacts are highly significant (Table 1.2).

Table 1.2: Major droughts and their impacts in the recent years throughout the world.

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[1] Source: http://www.un.org/sg/statements/?nid=6911

[2] Source: http://www.unccd.int/en/programmes/Thematic-Priorities/water/Pages/HLMNPD.aspx

Country	Year	Impacts
Namibia	2013	In May 2013 declaration of a national drought emergency, 14% of the population classified as food insecure.
United States	2012	The worst drought since the 1950s affecting 80% of the agricultural land. Increased world food prices (in US retail food prices increased about 4%), impact on food security and cost of living.
China P. Rep.	2010-2012	The Yunnan province Yunnan experienced a devastating drought, more than 6.3 million people affected (in some regions families water had to transport water from over 10km away), about 317 million US$ economic lost in the agricultural industry.
Horn of Africa	2000-2012	Dreadful droughts in the Horn. In 2011 the worst drought since early 1990s with nearly 13 million people affected. Severe droughts in Kenya during 2009 and 2011 whose agriculture was the most impacted (wheat yields dropping by 45%). In 2011 global acute malnutrition reached 37%, staple food price increased highly (in Kitui the price of white maize was 246% higher in May 2011 than a year ago), and about 3.5 million people required humanitarian assistance. In July 2011 famine was declared to two regions of southern Somalia, and 3.7 million (nearly half of the total population) were declared in crisis nationwide.
United States	2011	The Southern states have been affected (especially Texas,Oklahoma and New Mexico). The economic lossed reach 8 billion US$.
Russia	2010	The worst drought of the last 38 years, serious impacts on the environment, the economy and the human health.
Australia	2002-2010	Multi-year droughts, major impacts on agricultural production (in 2006 the wheat yield dropped by 46%).

Sources: FAO NRL Drought Factsheet (FAO NRL, 2012); JRC IES Food security bulletin. Special issue – Horn of Africa (JRC, 2011a); Statement of the UN's Secretary-General on World Day to Combat Desertification and Drought.

With regard to Europe, many European countries have experienced drought episodes of various significance (ranging from less to more severe), duration (a few months to years) and extend (local to regional to national) in the past 40 years (Kossida et al., 2012). Drought has often propagated from a meteorological hazard to an agricultural, hydrological and socio-economic (subject to the regional characteristics), while evidence shows that over the past 30 years drought's impacts have dramatically increased in the EU (with total costs €100 billion) (MedWSD, 2007), affecting not only in the South and Central EU, but also reaching now the North and Eastern EU (Kossida et al., 2012). Similarly, water scarcity affects a larger part of the EU: at least 11% of the European population and 17% of its territory have been affected by water scarcity to date. Recent trends show a significant extension of water scarcity across Europe (EC, 2007a). The year 2003 was the one with the highest number of countries affected in Europe (18 countries in total). More than 100 million people and one third of the EU territory were affected, while the cost of the 2003 drought to the European economy was at least € 8.7 billion. Similarly, in the year 2006 a high number of EU countries was impacted (14 countries), followed by 1992 (13 countries), 1995 (12 countries) and 2005, 1990, 1989 (11 countries). Most recently, drought occurrence was observed in 2014, 2012 and 2011. According to the drought analysis of the Joint Research Center (JRC) European Drought Observatory (EDO), between October 2013 and July 2014, the Southeastern Iberian Peninsula (Region de Murcia, Region de Valencia and eastern Andalucía) was affected by mean and long-term precipitation deficits, experiencing consecutive months of extreme dry conditions with potential impacts on reservoirs and river flows, while temporary rainfall shortages also occurred in France, Germany and Belgium (but their possible effects were likely insignificant due to subsequent rainfall events) (JRC, 2014). During the winter months of 2012, reduced rainfall, below the standard expected amount, occurred over extended parts of Southern (Iberian peninsula, South France, North Italy) and Western Europe, which in some cases (central Spain, England, western France) evolved into a prolonged dry spell with 6-month and 12-month rainfall totals being categorized as severely or extremely dry (JRC, 2012) This drought impacted Spain, Portugal, Southern France, Central Italy, Greece (locally), Hungary, Bulgaria and Romania, with affected areas also evident in Denmark, North Italy (Po river) and the Northern UK (JRC, 2012). During 2011 (period January to April), severe cumulated rain deficits were recorded in France (where 2011 is the driest year since 1975), England, Belgium, The Netherlands, Germany (Rheinland-Pfalz, Schleswig-Holstein, Niedersachsen, Thüringen), Denmark, Czech Republic (Stredocesky kraj, Severovychod), Slovakia (Vychodne Slovensko, Stredne Slovensko), almost all of Hungary and locally in Austria, Slovenia and Croatia (JRC, 2011b). These drought conditions continued into May 2011, with northern England, Wales, central-southern England, Denmark, northern Germany, central parts of the Ukraine and the western half of France experiencing a persistent shortage of 12-months of rainfall with possible impacts on reservoir storage levels in these regions (JRC, 2011c).

The social, political, environmental and economic costs of drought are evident across the globe. Drought impacts can be classified as direct or indirect. Reduced crop and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat are a few examples of direct impacts (Wilhite et al., 2007). Economic losses and social disruption are examples of indirect impacts. Another classification is based on the affected sector (i.e. environment, economy, and society) and thus the impacts may also be categorized as environmental, economic, or social. Environmental impacts include: depletion of available water resources (jeopardized minimum vital flow), degradation of water quality (eutrophication, seawater intrusion etc.), loss of wetlands and biodiversity, soil erosion and desertification, increased risk of forest and range fires, changes in river morphology (terraces, gullies), ground subsidence. The economic impacts relate to different economic sectors such as agriculture, industry, energy, navigation, tourism. They include: losses in production (crop & livestock, manufactured goods, energy, etc.) and respective losses in the income generated by the various economic activities (e.g. tourism), increases in prices of food, energy and other products (as a result of the reduction in supply, necessary imports or change of transportation modes due to low water levels in rivers), increases in water prices due to compensating measures, costs arising from mitigation measures (including water transfers, imports and other short term development options). Finally, the social impacts are diverse, such as: water shortage & interruptions due to deficiency in public water supply, population affected from water restrictions, public safety and health, food security, rising conflicts between water users, reduced quality of life, inequities in the distribution of impacts. In Europe, water scarcity and droughts have affected most economic sectors and various ecosystems. The most impacted sector is agriculture, followed by energy and public water supply; manufacturing industry is not reported to be widely affected (Kossida et al., 2012). Economic and social impacts are high, as well as environmental. Specific examples of experienced socio-economic and environmental impacts across the different European countries are provided below in Table 1.3 and Table 1.4 respectively.

Table 1.3: Socio-economic impacts of drought across European countries.

SOCIO-ECONOMIC IMPACTS

Sector: AGRICULTURE	**France (2011):** severe spring drought and the consequent water use restrictions in irrigation affected the yield and the quality of many crops (wheat, barley, corn and grain) and livestock farming (Audran and McLeod, 2011). At the end of May 2011, Credit Agricole (the farmers' bank) provided 700 million € in loans to aid ranchers. **United Kingdom (2011):** agriculture was the main economic sector affected. Field vegetables were affected in Yorkshire (later harvesting period, lower quality), yields of grazed and harvested grass for livestock production were reduced in parts of the south east, midlands and east of England, horticultural and cereal crops were also affected in some parts of southern and eastern England and voluntary restrictions on spray irrigators were implemented in the Fens. Due to the reduced production, feed prices raised and higher costs related to import had to be made (Environment Agency, 2011).
Sector: AGRICULTURE	**Portugal (2005):** during the summer large amounts of crops were destroyed because of drought (60% loss of wheat, 80% loss of maize production) (Isendahl and Schmidt, 2006). The costs of the 2004 and 2005 drought in agriculture were 519 million € (EC, 2007b). **Slovenia (2003):** the direct economic cost (mainly loss of agricultural production and aid to farmers) reached 100 million € (Sušnik and Kurnik, 2005). According to the 2007 Slovenian Revision Report on Drought Mitigation Measures the total economic cost of drought in the years 2000-2006 was estimated at 247 million € (86 million € for recovery measures; 3 million € for preparedness measures) (Gregorič, 2009). **Romania (2003):** agricultural production was mainly affected (i.e. wheat: 2500t/ha and rice: 0.5t/ha comparing to 7000t/ha and 10/ha respectively of a normal year) (Anon, 2009). **Finland (2002-03):** losses of 17 million € were reported for agriculture (EC, 2007b).
Sector: NAVIGATION	**Germany (2011):** in May 2011, the discharge of the rivers Rhine and Meuse decreased by 58% and 68% respectively, in comparison with the long term monthly average (Van Loon, 2011). As a result, ships in these rivers were forced to navigate at 20-50% of their capacity (Vidal, 2011). **Netherlands**: low river discharges during dry periods cause restrictions in the inland navigation disturbing transportation, loading and unloading, and leading to increased costs. Pumping of water to balance the water level of rivers between two locks is an additional cost. According to the Netherlands national drought study the long-term cost due to low water levels in the navigation sector is estimated at 70 million €, while the total cost can increase up to 800 million € in a year with extremely low discharge conditions (like the 1976)(Projectgroep Droogtestudie Nederland et al., 2005).

Sector: ENERRGY & INDUSTRY	**France (2009, 2005, 2003):** during the 2009 summer heat wave, due to cooling water shortages, the nuclear power generation industry faced a shortage of about 8 GW resulting in the import of electricity from Great Britain (Pagnamenta, 2009; Rübbelke and Vögele, 2011). In 2003, 15% reduction in the nuclear power generation capacity for five weeks, and 20% reduction in the hydroelectric production (Hightower and Pierce, 2008; Rübbelke and Vögele, 2011). Economic losses in the energy sector were estimated at 300 million € in 2003, and 270 million € in 2005 (EC, 2007b). **Germany (2003-2007):** During nine summer periods between 1976 and 2007 (1976, 1989, 1991, 1994, 1995, 2003, 2004, 2006 and 2007) the German government had to reduce production of nuclear power due to high temperatures of water and/or low water flow rates (Müller et al., 2007): 90% reduction at the Unterweser plant (June-September 2003), 60% at the Isar plant (for 14 days in 2006) due to excessively high temperatures and low stream flow rates in the river Isar (Forster and Lilliestam, 2009). **Portugal (2004-2005):** hydropower production was 37% and 54% lower than the average in 2004 and 2005 respectively. The costs of these droughts on industry and energy were 32 and 261 million € respectively (EC, 2007b). **Europe (2003):** extremely high summer temperatures, precipitation deficits (IPCC, 2008) and low streamflow rates impaired the generation of electricity in more than 30 nuclear power plant units in Europe, due to limitations in the levels of cooling water discharge (IAEA, 2004). To continue their operating activities some nuclear power plants got exemptions from legal requirements. **Romania (2003)**: the sole nuclear reactor in Cernavoda on the Danube River was put out of function due to low water levels (Anon, 2009). The need to change the transportation method increases the price of products affecting almost the entire industrial sector. **Norway, Sweden, Finland (2002-2003):** considerable decrease in hydropower production, consequent increase in the price of electricity (Kuusisto, 2004). In Finland losses of 1 and 50 million € were reported for industry & energy respectively (EC, 2007b).
Sector: TOURISM	**Cyprus (2011):** a brief web-based survey (Bruggeman et al., 2011) was carried out 23 establishments. 83% of the participants mentioned that minor to major problems have occurred during drought periods of the last 15 years. As a response they have installed water saving devices in their accommodation (water-efficient showerheads, dual flush toilets, water saving taps, toilet cistern bags), trained their staff and informed their clients to use water wisely. **France (2006-2007):** losses of 144 million € were reported in the Savoia skiing area in the Alps.

Sector: PUBLIC WATER SUPPLY	**France (2011):** restrictions on water use were imposed in 78l administrative which lasted very long (18 weeks = 1/3 of a year) (Ministère de l' Écologie, du Développement durable, des Transports et du Logement, 2011). **Cyprus (2008-2010):** in 2008 8 million m^3 were imported from Greece as an emergency measure to water shortage. The total cost for short-term emergency measures) to enhance domestic water supply (taken in 2009 and 2010 was estimated at 287 million €. Restrictions of to the domestic use were applied, limiting the supply to households to only 36 hours per week. **Spain(2008):** some reservoirs **in Catalonia** (supplying 5.8 million inhabitants) reached 20% of their capacity resulting in restriction in domestic water uses, such as swimming pools and gardening, as well as public water uses, i.e. fountains (Collins, 2009). **Spain and Portugal**: the Tagus-Segura water transfer in Spain raised conflicts between the autonomous communities of Castilla-La Mancha and Murcia and also created tensions between Spain and Portugal concerning the flow regime (Isendahl and Schmidt, 2006). **Portugal (2004-2006):** the cost for public water supply was 23.2 million €, while 22,850 tankers were used to support urban water supply in 66 municipalities with 100,500 inhabitants. The cost of the inconvenience to the inhabitants affected was considered to be significantly higher than the direct costs reported (De Marsily et al, 2007). **Finland (2002-2003):** losses of 10 million € were reported for public water supply (EC, 2007b)

Source: Kossida et al., 2012.

Table 1.4: Environmental impacts of drought across European countries.

ENVIRONMENTAL IMPACTS	
Sector: AGRICUL TRE	**Portugal (last decades)**: In the Ribeiras do Algarve River Basin increased water demand for agriculture and tourism during the last decades has caused serious pressure on the area's environment, including aquifers' over-abstraction, salinization and water resources' degradation.

Sector: PUBLIC WATER SUPPLY	**Spain**: For over the last 40 years groundwater overexploitation in the southern part of Spain has an enormous ecologic impact on the area (Ibáñez and Carola, 2010), related to significant lowering of groundwater tables, drying out of springs, degradation of wells and boreholes and saltwater intrusion**.** **Italy:** The problem of salt water intrusion due to over exploitation is very common in several coastal aquifers of Italy (Antonellini et al, 2008). In the coastal areas in Sardinia, Catania Plain, Tiber Delta, Versilia and Po Plain freshwater resources are becoming scarcer due to drought, over-exploitation and salinization. **Malta:** because of high water demand resulting in over-abstraction, main groundwater bodies face the risk of failing to achieve the environmental objectives of the WFD (MEPA and MRA, 2011). The total annual and investment cost of basic and supplementary measures proposed by the Water Catchment Management Plan for the Maltese Inland in order to mitigate quality degradation of water bodies and water deficit due to over-abstraction is calculated at 231.8 and 22.30 million €, respectively (MEPA and MRA, 2010). **Cyprus (2008)**: In 2008 after a prolonged period of drought affecting mainly the agricultural and domestic sectors, the island's water resources ended up extremely over-exploited: major dams such as Kouris, Yermasoyia and Dipotamos Dams dried out, groundwater has declined by 40% and aquifer salinization was detected (Pouros, 2008).
Sector: FORSTRY	**Romania (2007, 2009):** these severe drought events are reported to negatively affect forest areas causing changes in the area of several tree species and the boundaries of vegetation zones (moving North and West of the silvo-steppe), encouraging also the appearance of certain Saharian species in the South area of Romania (Lupu et al., 2010). Hills and plains covered with forests in areas of South and East Romania, such as Dolj, Olt, Galati, Braila, Ialomita, are proved to be very vulnerable to drought. This vulnerability not only affects the environmental balance but also has a negative socio-economic impact on the population. **Lithuania (2002):** during the summer drought, 123 forest and peat bog fires burst out in July 2002 and 374 in August (Sakalauskiene and Ignatavicius, 2003). **Czech Republic (2003-04):** during these dry years an increased defoliation of tree species was noticed, especially dieback of unoriginal spruce forests and Pinus nigra. Forests weakened by drought were more vulnerable and consequently attacked by Armillaria ostoyae and bark-beetles (Czech Republic National SD Report, 2008).
Sector: AQUATIC ECOSYSTEMS	**Portugal**: according to a research conducted from June 2003 to March 2008 in the Mondego estuary, drought conditions have a significant impact on fish communities causing disturbances in their behaviour and functions (Baptista et al, 2010). More specifically, during drought periods due to increased salinity inside the estuary and low freshwater flows the estuarine brackish habitats moved to more upstream areas, while in downstream areas new marine adventitious species were found. Moreover, freshwater species no longer existed inside the Montego estuary during drought, and lower densities were observed for most of the species. **Portugal (2004-2005)**: the drought resulted in a water level fall in many reservoirs (two major reservoirs, Funcho and Arade, completely dried out), reduced river flows with a parallel degradation in their quality consequently affecting migrating species (e.g. lamprey in the Minho river), water table decline in aquifers, saltwater intrusion in transboundary waters bodies (e.g. Tagus Estuary), forest fires and the removal of 220 tons of fish (De Marsily et al., 2007).

Source: Kossida et al., 2012.

1.1.2 The policy context: towards improved drought management

Responses and adaptation measures are needed to mitigate drought (and water scarcity) impacts, but these may differ substantially, depending on the issues and priorities of each region. The state of implementation of response measures to mitigate the impacts of drought and water scarcity, the selected management approach, as well as the prevailing policy and institutional frameworks differ among the different countries. Furthermore, the effectiveness of the response measures is difficult to be evaluated as it is related to many socio-economic factors.

Traditionally, most attempts to manage drought and water scarcity, and their related impacts, focused on a rather reactive crisis management approach resulting thus in being ineffective, untimely and unsustainable on the long term. Typically, when drought occurs, governments followed with impact assessment, response, recovery and reconstruction activities to return the region or locality to a pre-disaster state. In their Report on National Drought Management Guidelines, WMO and GWP quoted that "*Historically, little attention has been given to preparedness, mitigation or prediction/ early warning actions (i.e. risk management) and the development of risk-based national drought management policies that could avoid or reduce future impacts and lessen the need for government and donor interventions in the future. Since societies have emphasized crisis management in past attempts at drought management, countries have generally moved from one drought event to another with little, if any, reduction in risk. In addition, in many drought-prone regions, another drought event is likely to occur before the region fully recovers from the last event. If the frequency of drought increases in the future, as projected for many regions, there will be less recovery time between these events*" (WMO and GWP, 2014).

There are many factors which have led to poor drought management, and these relate both to the nature of drought hazards, as well as to the management approach traditionally adopted, and the underlying legislative background and institutional capacities. These include:

- The lack of a universally accepted definition confuses managers and decision-makers with regard to characterizing the degree and severity of drought. Thus, it is more realistic to tailor drought definitions on the basis of the characteristics of a region and the experienced impacts (Wilhite and Glantz, 1985), but this requires in turn a thorough analysis at the regional/local scale, and the availability of necessary data and science.

- The slow onset of drought (creeping phenomenon) and its end are difficult to identify, leading to confusion on when/where a drought should be declared. As drought impacts may last long after the hydrometeorological variables (e.g. precipitation, soil moisture) return to normal conditions, defining the time span of a drought event is even more complex.
- The quantification of drought impacts is challenging (not straight forward as in other natural hazards), since these impacts can affect the society, the economy and the environment for months to decades after the physical phenomenon has ended, spatially extending over large areas, and varying in type and magnitude (Wilhite et al., 2014).
- The lack of knowledge and public awareness pose additional constraints. Stakeholders, and the general public, are often unaware of the wide range of drought consequences which adversely affect the environment, the economy and the society.
- The lack of concrete methodologies on drought risk management and planning at the national and regional levels, and the lack of robust drought policy frameworks.

The above elements make it thus difficult for scientists, water managers, policy and decision-makers to adopt a timely response based on early warning, vulnerability and impact assessment, and disaster cost estimation. Wilhite et al. (2014) identify three types of drought policy response. The first and most common approach, followed by both developing and developed nations, is post-impact government (or non-government) interventions, i.e. **reactive approach**. These interventions focus on relief measures in the form of emergency assistance, providing money or other specific types of assistance to the drought victims. This reactive approach is seriously defective in terms of vulnerability reduction since it only addresses the symptoms and does not act as a driver to change behaviors and/or management practices. A second type of drought policy approach is the development of **pre-impact or risk management programs that are intended to reduce vulnerability and impacts**, i.e. **mitigation measures**. Mitigation in the context of drought relates to risk management, and focuses on identifying where vulnerabilities exist (particular sectors, regions, communities or population groups) and addressing the related risks through systematically implementing mitigation and adaptation measures that will alleviate the risk associated with future drought events. There are numerous and diverse drought mitigation measures, but are often less obvious to the affected population and stakeholders since often non-structural. These include, but are not limited to: development of early warning systems, seasonal drought monitoring and forecasting, demand management and water saving, planning for additional and/or alternative water supply, increasing water storage capacity, drought insurance schemas, awareness raising and education, etc. An exhaustive list of these measures is presented in Wilhite and Rhodes, 1993, compiled after the occurrence of several drought episodes in the US in the late 1980s and early 1990s. The third type of policy response is the **development and implementation of preparedness plans and policies**, which include **organizational frameworks and operational arrangements** developed in advance of drought, maintained and updated between drought episodes by government or other entities. This approach aims to create greater institutional capacity through improved coordination and multi-disciplinary collaboration between government, stakeholders, private entities, beneficiaries and the affected communities.

Table 1.5: Overview and characteristics of the different drought response types

Response Type	Approach	Associated Measures	Effectiveness
Post-Impact / Reactive	**Crisis Management**	**Relief measures:** Economic, food or other types of assistance to the drought victims and impacted communities	Short-term
Pre-Impact / Mitigation	**Risk Management**	**Mitigation measures:** - Early warning systems - Monitoring and forecasting - Demand management and water saving - Additional and/or alternative water supply - Increasing water storage capacity - Drought insurance schemas - Awareness raising - Education, etc.	Short to medium-term

Proactive planning/ Preparedness	**Risk Management**	**Development of National Policy and DMPPs:** - Development & Implementation of a National Drought Policy - Development & Implementation of Drought Management and Preparedness Plans (DMPPs) - Identification and implementation of advanced regulatory and economic instruments - Institutional capacity building, governance and operational arrangements	Medium to long-term

The need to move towards a more efficient risk-based drought management has been recognized at the higher policy level by the World Meteorological Organization (WMO), the United Nations Convention to Combat Desertification (UNCCD) and other actors. The High-level Meeting on National Drought Policy (HMNDP, held in March 2013) main findings and conclusions, as formulated in the Final Declaration (HMNDP, 2013a), are summarized below:

- There are insufficient policies for appropriate drought management and pro-active drought preparedness in many countries around the world. Countries continue to respond to droughts in a reactive crisis management mode, and they need to understand the necessity of improved risk management strategies and develop preparedness plans to reduce drought risks.
- There is a need for urgent inter-sectoral coordination of the assessment of drought vulnerability and impact assessment.
- The identification of relief/ emergency measures that will reduce the impact of current droughts is still relevant, yet these need to be synergetic with preparedness, mitigation and adaptation actions for long term resilience.
- Effective drought policies are necessary and included in the context of: the Rio+20 follow-up to improve the implementation of Integrated Water Resources Management; the UNCCD to combat land degradation and desertification and mitigate the effects of drought; the UNCCD Conference of the Parties Decision COP10 to formulate an Advocacy Policy Framework (APF) on drought; the Global Framework for Climate Services (GFCS) to strengthen climate prediction and services.

- Governments around the world are encouraged to develop and implement National Drought Management Policies (NDMPo), consistent with their national development laws, conditions, capabilities and objectives. It is recommended that these are centered around 5 goals (HMNDP, 2013b): (1) Proactive mitigation and planning measures, risk management, public outreach and resource stewardship; (2) Greater collaboration to enhance the observation network and information delivery system and to improve public understanding of and preparedness for drought; (3) Incorporation of comprehensive governmental and private insurance and financial strategies into drought preparedness plans; (4) Recognition of a safety net of emergency relief based on sound stewardship of natural resources and self-help at diverse governance levels; (5) Link to drought programs and other related policies and response in an effective, efficient and customer-oriented manner.
- The WMO, the UNCCD, the UN FAO, and other related UN agencies, programs and treaties, as well as other concerned parties, are urged to assist governments, especially the developing countries, in the development of National Drought Management Policies and their implementation. Similarly, developed countries are urged to assist the developing countries, and international cooperation is encouraged.

1.2 Scope and objectives of the dissertation

1.2.1 Specific Objectives

The overall objective of the current research is to **develop operational methods and tools for supporting drought risk management in water stressed areas**. It proposes a holistic methodology based on the basic concepts of mainstreaming (UNDP, 2011) and develops a set of relevant tools for proactive drought risk management and planning, implementing a step-wise approach that integrates physical and anthropogenic drivers and pressures, impacts and response.

The elaborated methods and tools cover all components which need to be accounted for in drought risk management, spanning from the drought hazard evaluation, to the assessment of water resources availability and demands across economic sectors, to mapping of water scarcity vulnerability and developing drought risk profiles, and finally leading to the design of optimal mitigation measures, linking them to the decision-making process in order to set policy targets for internalizing them into development programming frameworks.

To achieve this goal the following specific objectives have been defined:

1. Propose a generic process for mainstreaming Drought Risk Management and define its subsequent steps, drawing on the principals of the UNDP, which can serve as a basic roadmap for the stakeholders.
2. Develop a methodology to accurately characterize and map Drought Hazard, based on operational and easily reproducible precipitation-derived indicators, capturing all drought characteristics (frequency, intensity, magnitude, duration, speed of onset). Develop a new drought hazard indicator, the DHI.
3. Demonstrate the input that elaborated Water Resources Management Models (WRMM) can provide in defining vulnerability, by supporting detailed assessments of the status and evolution of water balance trends, and a detailed picture of the temporal and spatial extent of unmet demand per economic sector. The latter is an important component in defining vulnerability. Identify the necessary features and capabilities of the modeling frameworks to be used in this process. Identify the components/ parameters of the water cycle and water balance (outputs of the WRMM) which are important inputs in assessing vulnerability (e.g. unmet demand, water supply reliability) in water stressed

areas. Discuss on the capacity of the WEAP21 software to act as a modeling environment for building robust distributed node-based Water Resources Management Models (WRMM) suitable for such applications, also in area.s with limited data.

4. Develop an analytical framework for the characterization and mapping of Drought Vulnerability, blending socio-economic indicators which reflect exposure and sensitivity, in line with data fed by the WRMM. Develop a new drought vulnerability indicator, the DVI, that can be used for assessing vulnerability
5. Develop a Drought Risk Profile, by overlaying the drought hazard and vulnerability components, and define relevant thresholds and classes.
6. Provide a generic methodology for designing Demand Management Options (i.e. interventions and measures covering management, technological and economic aspects) for the urban and agricultural sectors, incorporating the development of cost-effective intervention curves, able to be adjusted under different regional context and expert input from stakeholders.
7. Test/simulate the impact and effectiveness of the interventions against specific criteria within the WEAP21 software. Provide suggestions how to embed/model them within the WEAP21 software.
8. Link interventions to the decision-making process: Support decision making by developing a Decision Support Platform, linking the Water Resources Management Models (WRMM) with the Matlab optimization toolbox, with the purpose of identifying a bundle of optimal mitigation measures for demand management. Develop and apply an optimization algorithm to optimize measures' allocation across a target area on the basis of the cost-effective intervention curves.
9. Internalize DRM into development framework: Test the robustness of the optimization results under future climate and socio-economic scenarios (drawing on EU accepted scenarios) and identify indicative Policy Targets.
10. Assess the reduced drought risk as induced by the proposed adaptation policy.
11. Draft suggestions how to implement DRM in actions, development programs, policy etc., and how to monitor the impacts of DRM mainstreaming.
12. Test the suggested methodology and tools in a pilot area in Greece, namely the Ali-Efenti basin in the Northwestern Thessalia River Basin District.

1.2.2 Selection of the pilot area for testing the methodology

The overall methodology of the current research, and its individual sub-components, are tested in the pilot area of the Ali-Efenti basin (Northwestern part of the Pinios River) in the Thessaly plain in Central Greece. This basin has extended irrigation areas (the main crop cultivated here is cotton), while irrigation efficiency is low. Imbalance between demand and availability (water stress) is frequent, and the unmet demand is highly pronounced during the summer period. As a result, over-abstraction has led to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels. The main issues in the pilot area are summarized below:

- The intense and extensive cultivation of water demanding crops has led to a remarkable increase in irrigation water demand leading to over-exploitation of groundwater resources. The summer water deficit is well pronounced.
- The over-exploitation of groundwater has led to the deterioration of the already disturbed water balance and the further degradation of water resources with declining groundwater levels.
- Drought episodes are frequent in the area, while desertification is becoming an issue.
- The area has competing water uses, irrigation being the predominant one, and is classified among the most productive agricultural region of Greece, thus socio-economic impacts of drought are a major challenge.
- Drought Management Plans or other policy instruments are lacking, and drought management is currently based on “crisis management” rather than on a pro-active and preparedness approach.
- An improved water allocation schema, with water gains resulting from the application of selected demand management measures can alleviate the problem of water stress and leverage economic losses.

Based on the characteristics and current state of the Ali-Efenti basin (as described above) it is ruled as a suitable area to develop and test the envisioned research products and tools.

1.2.3 State-of-Art and Innovative elements

The following innovative elements have been developed in relation to the current research:

- Elaboration on the UNDP concept of "Mainstreaming Drought Risk Management (DRM)".
- Development of a roadmap on mainstreaming DRM useful to stakeholders.
- Development and provision of operational methods and tools for mainstreaming DRM.
- Development of the operational Drought Hazard Indicator (DHI) and associated methodology to characterize and map Drought Hazards.
- Development of the Drought Vulnerability Indicator (DVI) and associated framework, blending socio-economic indicators which reflect exposure and sensitivity, adaptable to different socio-economic context.
- Development of a methodology for elaborating and mapping Drought Risk Profiles, by overlaying the aforementioned drought hazard and vulnerability components.
- Development of a methodology for the design of generic "intervention curves" in the urban and agricultural sector integrating a bundle of demand management measures.
- Investigation of the effect of introducing of alternative crops (aloe vera, broccoli, kiwi) to substitute part of existing water intensive crops as a potential demand management solution.
- Input on how to simulate the above mentioned intervention curves (i.e. demand management measures) in WEAP21 through user-defined parameters (scripting in WEAP21).
- Development of a Decision Support Platform by linking WEAP21 with Matlab software.

1.3 Structure of the dissertation

This dissertation is structured around 9 chapters. An overview of the chapters and their brief description is presented below.

Chapter 1: Introduction

This chapter provides an introduction and defines the relevant context of this dissertation. The physical and policy context is discussed here, along with the scope, the rationale and the specific objectives of the research. State-of-art and innovative elements of the research are also highlighted.

Chapter 2: Drought Policy in Europe

This chapter presents the European policy on water scarcity and drought. An analysis of the shortcomings of the EU Water Framework Directive (WFD) EC/2000/60 in dealing with drought issues is presented, as well as a detailed roadmap of the EC policy-level activities and initiatives in relation to water scarcity and drought. Finally, the specific objectives of the 2007 EC Communication on water scarcity and drought is presented, along with an analysis of the 2012 Policy Review and the progress achieved.

Chapter 3: Methodological Approach

This chapter discusses the overall methodology developed in the framework of the current research for mainstreaming drought risk management. Starting with the presentation of the basic concepts of drought risk management and the current challenges and gaps (literature review), this chapter presents an overview of the methodological approach, articulating the different steps and their interrelation. Further details for the methodology of each step are provided in the subsequent chapters 4-7.

Chapter 4: Definition and development of a Drought Risk Profile (DRP)

This chapter elaborates the development of an analytical framework for the characterization and mapping of drought risk. It presents the steps, and relevant methodology, to develop a Drought Risk Profile (DRP) incorporating the: (a) identification and mapping of the drought hazard; (b) the assessment of the water resources' availability and demand (i.e. water balance) at a disaggregated spatial and temporal scale; (c) the integration of socio-economic components into finally defining water scarcity and drought vulnerability and risk. The proposed methodology for developing Drought Risk Profiles has been tested in the Ali-Efenti pilot area. The methodology is generic and can be extrapolated to drought prone areas. It is based on the use of operational indicators which capture all drought hazard components (recurrence, magnitude, severity, duration) and further integrated with socio-economic components (derived through suitable modelling approaches where necessary) to assess the associated vulnerability and risk.

The correct identification of the balance between water resources' availability and demand (either deficit of surplus) has been considered an important socio-economic component in the above integration process, as it lies at the heart on any drought risk assessment and drought management plan. Data scarcity per sector and user often prevents the accurate calculation of this component/indicator, and raises the need to develop suitable modeling environments, capable of assessing the availability of water resources across time and space. The accurate representation and simulation of all the necessary physical and anthropogenic characteristics is challenging and calls for flexibility and adaptability of the modeling tools. The ability of the state-of-art tool WEAP21 to support such modeling applications in data scarce areas, representing all the salient features of the hydrological cycle, is also discussed in this Chapter. Furthermore, its selection as a central component of a Decision Support System is justified by highlighting the capacities it offers in this context (e.g. scenario building function, possibilities to add user defined parameters, API, etc.).

Chapter 5: Design and simulation of mitigation measures

This chapter elaborates the investigation of the effect of a "Demand Reduction Policy", including land use change, based on a bundle of technological and management measures which promote water saving and efficiency gains in the urban and agricultural sectors. A methodology for designing generic "intervention curves" in the urban and agricultural sectors, integrating a bundle of demand management measures, is developed. The intervention curves simulate the potential benefits (in terms of water saving) and costs of the selected bundles of measures as a result of an optimization process. Linking of the intervention curves to the WEAP21 software is also discussed, by elucidating how to simulate the above mentioned intervention curves through user-defined parameters in WEAP21 (scripting in WEAP21). Testing of the methodology in the Ali-Efenti basin has also been implemented: the selected bundles of measures have been simulated and assessed for their impact on the pilot area (through the use of the WRMM).

Chapter 6: Prioritizing mitigation options: Optimization and Decision-making

This chapter brings together the core elements of the proposed Decision Support System (DSS) to be used for mitigating drought risk, supporting decision-making and setting of policy targets. A MATLAB Optimization module linked to the WEAP environment is developed, in order to rule on the optimum selection of demand management interventions across the urban and agricultural sectors. This tool allows stakeholders to design mitigation options and policy targets by screening through their preferences and constraints (e.g. available investment cost, life-time of interventions, integration potential within the users, etc.). Finally, the methodology is trialed in the Ali-Efenti basin.

Chapter 7: Internalizing Drought Risk Management: Definition of policy targets and implementation

This chapter presents options for testing the robustness of selected solutions (of the previous chapter) through the elaboration of future climate and socio-economic scenarios. On the basis of the robustness results policy targets are defined, followed by a process for investigating the potential integration of the DRM elements into the national development framework, the national and regional policy and the sectoral strategies. Different approaches and methodologies are discussed. Finally, means and metrics of monitoring the impacts of the DRM mainstreaming (either in terms of changes in the adaptive capacity or in the policy development process/ chain) are discussed.

Chapter 8: Testing of the methodology in the Ali-Efenti pilot catchment

This chapter presents the testing of the developed methodology in a pilot area in Central Greece, namely the Ali-Efenti catchment of the Pinios River Basin. All the steps of the methodology (presented in the previous chapters 3-7), including the development of a Water Resource Management Model (WRMM) for the Ali-Efenti catchment, have been applied here for testing its applicability and validity on a physical-basis context. The results and findings for the Ali-Efenti catchment are presented and discussed.

Chapter 9: Conclusions and Recommendations

This chapter consolidates the main results and conclusions of the research, within and across all the methodological steps. It further discusses the added value of the proposed methods and tool in decision making towards mitigating drought and water scarcity risk, and adopting a proactive approach. Finally, it touches on policy making issues, by scrutinizing specific policy objectives tackled by the developed products and tools, and presenting possible integration approaches of the foreground in the policy-making process chain.

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CHAPTER 2 – DROUGHT POLICY IN EUROPE

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2 DROUGHT POLICY IN EUROPE

2.1 Limitations of the EU WFD in addressing drought and water scarcity issues

The flagship water legislation in Europe is the EU Water Framework Directive (WFD) EC/2000/60 (EC, 2000), adopted by the European Parliament and the Council in 2000 as a legal document establishing a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. The adoption of the EU Water Framework Directive (WFD) in 2000 was a major landmark which established new requirements for integrated river basin management and planning in order to achieve ecological objectives. The aim of the WFD is to maintain and improve the aquatic environmental of the Community, setting out the target of achieving "good status" for all surface and groundwater bodies by 2015. The introduced term "good status" refers to a new concept of ecologic quality, which is based on biological, chemical and physical information, but its interpretation by the Member States has raised confusion. To achieve good status, the WFD urges the Member States to assess the status of their water bodies, draft River Basin Management Plans (RBMPs) and implement programmes of measures (PoM) when necessary. These actions are primarily concerned with the quality of the waters. Control of quantity is an ancillary element in securing good water quality and therefore measures on quantity, serving the objective of ensuring good quality, should also be established as stated in the *Consideration 19*. A major milestone in the implementation of the WFD was reached in December 2009, which was set as the deadline for delivery of the River Basin Management Plans (RBMPs). More than half of the EU Member States succeeded in adopting their RBMPs on time. These plans are supposed to be the main instrument for establishing a new water management regime that sets ambitious environmental objectives – a move away from processes to the delivery of tangible results (Scheuer and Naus, 2010).

The WFD considers that common principles are needed in order to coordinate Member States' efforts to improve the protection of Community waters in terms of quantity and quality, to promote sustainable water use, to contribute to the control of transboundary water problems, to protect aquatic ecosystems and to safeguard and develop potential uses of the Community waters (*Consideration 23*). Furthermore, it recognises that for the purposes of environmental protection there is a need for better integration of qualitative and quantitative aspects, of both surface and groundwater, taking into account the natural flow conditions of water within the hydrological cycle (*Consideration 34*). Although the above priorities clearly set the scene for an integrated water resources management where water quantity (in terms of balance between water availability and demand) is a central consideration in the analysis and the development of appropriate management plans, drought and water scarcity mitigation have in reality a marginal role within the WFD. There are several articles within the WFD where water quantity issues relating to drought and water scarcity are mentioned, yet they lack specific problem-oriented context, or they are loosely inter-related and thus cannot serve the purpose of properly addressing the challenge of water scarcity and drought. In the section below, the most relevant reference on water quantity extracted from the WFD are presented and commented in relation to their potential contribution in tackling water scarcity issues.

Article 1 states that among the purposes of the Directive are the protection of the aquatic ecosystems (thus sufficient water quantity which is a main driver must be secured), the promotion of sustainable water use (thus rationalising and optimising water demand and abstractions which are a significant pressure for water scarcity) and the contribution to the mitigation of drought effects (thus facilitating appropriate decision making and adoption of pro-active or reactive response measures to cope with the problem).

What is interesting to notice is that the definition of "good surface water status" (as presented in *Art. 2.18*) refers to the status achieved by a surface water body when both its ecological and chemical status are at least good, while the definition of "good groundwater status" refers to the status achieved by a groundwater body when both its quantitative and chemical status are at least good. Furthermore, in *Article 4b(ii)* it is explicitly mentioned that MS shall ensure a balance between abstraction and recharge of groundwater with the aim of achieving good groundwater status. In the relevant Annex V, with regard to the classification of the groundwater quantitative status, the defining element is the level of groundwater as metrics of the available resources compared to the long-term annual average rate of abstraction. It thus seems that quantitative issues are more coherently addressed for the groundwater bodies (this statement is also supported by *Art. 8.1*) enhancing thus the visibility of the potential pressures and impacts of drought and water scarcity on groundwater.

Article 4.6 addresses prolonged droughts (as well as extreme floods) as an exceptional or reasonably unforeseen "force majeur" which qualifies for an exemption from the WFD requirements. Thus, the temporary deterioration of water bodies' quality status is not considered a violation of the requirements in such cases. This article is very loosely defined and raises ambiguity and confusion. First of all, it appears to be in disagreement with the overall goal of proactive water resources management where forecasting and preparedness towards such events and circumstances is a main principle. Prolonged drought is indeed a valuable exit clause, nevertheless it should not be used abusively just to serve this purpose. Managing the water resources promptly should also incorporate low resource scenarios in the planning and decision making process, and such sub-plans should be embedded in the river basins management plans. Secondly, the term "prolonged drought" is not clearly defined in the WFD and is thus prone to abuse. Homogenised indicators or at least common criteria for demonstrating such circumstances based on proved evidence should be laid out and wisely defined. The WFD although in principle lays out a legitimate exemption clause, fails indeed in defining a robust interpretation for its optimal use.

Article 7.1 requires MS to identify within each RBD all the water bodies which are used for abstraction of more than 10m^3 of drinking water per day (or serving more than 50 people), and furthermore to monitor those which provide more than 100m^3 per day on average. Although this monitoring purpose is set in order to secure drinking water quality standards, the identification of these abstractions in meaningful when dealing with water scarcity situations in terms of both water allocation and protection of the most vulnerable resources in terms of designated water use (i.e. securing drinking water supply may be more important than securing an industrial one).

In *Article 8.1*, where the MS are asked to ensure the establishment of monitoring programs by 2006, there is a clear distinction between the requested parameters to be monitored; the groundwater monitoring programs shall cover monitoring of the quantitative and chemical status, whereas for surface waters such programs shall cover ecological and chemical status monitoring, while monitoring of their volume and level (or rate of flow) is only required to the extent relevant for ecological and chemical status and ecological potential. This article which is in line with the requirements for the groundwater bodies set in *Articles 2 and 4* demonstrates again that quantitative issues are more holistically addressed when it comes to groundwater bodies. Monitoring of the groundwater levels is an important element in the definition of the onset and offset of a drought and the assessment of the impact of reduced rainfall. Groundwater is known to respond slower to the meteorological changes. Thus, when groundwater systems are affected by drought, decreases in groundwater recharge are observed, followed by declining groundwater levels and a respective decrease in groundwater discharge.

Monitoring of groundwater level in this respect is a valuable indicator and, when compared with other indicators, could inform on the spatiotemporal evolution of drought events.

Article 5 requires an economic analysis of the water uses within the RBD, while along the same principles *Article 9* (and *Annex III*) requires the recovery of the cost of water services (including environmental and resources costs) to be taken into account in accordance to the polluter pays principal. It foresees that the MS should take into account long-term forecasts of supply and demand for water in the RBD and, where necessary, ensure by 2010 at the latest, that water pricing policies provide adequate incentives to use water resources efficiently, and that various economic sectors contribute to the recovery of the costs of water services, including those relating to the environment. In the context of water scarcity, these articles address both drivers and response measures. Long term forecasts of supply and demand are clearly associated with the drivers of water scarcity and drought, namely climatic changes (which can increase demand and reduce supply), population change (growth, migration, urbanisation), living conditions (economy, social perception, education), current practices. A thorough analysis of such forecasts should incorporate all these drivers which can ultimately change the water consumption patterns, and the fact that the WFD addresses these issues is an important milestone for any future drought management planning. On the other hand, water pricing policies are an effective response measure (along with other economic, technical, legislative and educational instruments) which can ultimately initiate a change in the aforementioned drivers.

Water quantity issues are further underpinned by the PoMs (to be established by 2009 and further updated in the next implementation cycles), which according to *Article 11* shall promote an efficient and sustainable water use (*Art. 11.3c*), control the abstraction and impoundment (*Art. 11.3e*) as well as the artificial recharge (*Art. 11.3f*), and can be supplemented by additional measures with the aim of achieving the environmental objectives (*Art. 11.4*). A non-exclusive list of supplementary measures is provided in *Annex VI B* where demand management, efficiency and reuse measures are proposed among others. Such measures clearly allow the interaction between the different response instruments (economic, technical, legislative, educational) and facilitate the mitigation of drought and water scarcity impacts, setting the scene towards more elaborated and problem specific measures (e.g. leakage management, quotas etc.)

Finally, *Article 13.5* calls for the production of more detailed programmes and management plans dealing with particular aspects of water management to supplement the RBMPs. Under this provision, a specific Drought Management Plan (DMP) could be used, when and where needed, embedded or supplementary to the RBMP. The Directive gives the option to create such plan on a selected spatial scale which can differ from the RBD (e.g. sub-basin) or for a specific water type, thus resolving some scaling issues which can relate to the drought occurrence. Nevertheless, the importance of DMPs is not stressed nor any harmonised guidelines are provided.

It is currently recognised, as also demonstrated in the previous analysis, that the WFD is not fundamentally designed to tackle water quantity issues directly (Rossi, 2009; MED JP WFD/EUWI, 2006a), but rather indirectly (through achieving good status) as its purposes (*stated in Art.1*) include the protection of the aquatic ecosystems' status, the promotion of sustainable water use (thus rationalising and optimising water abstractions) and the contribution to the mitigation of the effects of floods and droughts. To counterbalance these limitations, additional legislation on floods has been formulated, namely the European Directive on the Assessment and Management of Flood Risks EC/2007/60 (EC, 2007c), while water scarcity and drought issues still remain untackled at the EU policy level. Looking in the context of water scarcity and drought (WS&D) phenomena, it is clear that their characteristics make it difficult to properly address drought and water scarcity mitigation through a water quality oriented management schema, such as the WFD, and rather call for focused problem-oriented policy recommendations. In this respect, the WFD can set the scene and provide a first instrument for addressing drought and water scarcity management while the necessary measures taken by the Member States can be prescribed under its legal umbrella, yet it does not provide the means to fully address the problem (covering all aspects of it) and operationalise some of the proposed measures (**Table 2.1**). Evidence from the assessment of the first cycle of the WFD regarding aspects of WS&D in the RBMPs[1] also supports these conclusions (Schmidt and Benitez, 2012): while WS&D are recognised in many RBMPs as relevant issues the two phenomena are not well differentiated, nor substantially addressed, and the quantitative datasets are incomplete in many plans. The plans are insufficient for pro-active planning, while the majority of measures applied by the Member States target pressures, state and impacts, and only very few measures target key drivers. The sources of funds to implement the relevant measures are not specified in the majority of the RBMPs. The influence of other sectoral policies on the reduction of water scarcity and the mitigation of drought effects is not

[1] A total of 123 RBMPs (encompassing approximately a 58% of all EU River Basin Districts) have been assessed from the following 25 countries: AT, BE, BG, CY, CZ, DE, DK, EE, ES, FI, FR, HU, IE, IT, LT, LU, LV, MT, NL, PL, SE, SI, SK, UK, NO.

yet addressed. Finally, in the case transboundary river basins there is still a major gap in dealing with these issues.

Table 2.1: Drought management aspects (and associated response types) underpinned by the WFD.

<table>
<tr><th></th><th colspan="3">DROUGHT RESPONSE TYPES</th><th>Is this aspect covered by WFD?</th></tr>
<tr><td>Drought characterisation</td><td>Post-impact/ Reactive crisis management</td><td rowspan="2">Pre-impact/ Mitigation-based risk management</td><td rowspan="4">Proactive planning/ Preparedness-based risk management</td><td>Partially (definition of prolonged drought)</td></tr>
<tr><td colspan="2">Identification of mitigation measures</td><td>As supplementary measures. Not real focus on demand management</td></tr>
<tr><td colspan="3">Proactive planning/ Drought Management Plans (DMPs)</td><td>The development of ancillary DMPs is mentioned, but not a focus on drivers</td></tr>
<tr><td colspan="3">Operationalisation (Drought Policy, Regulatory & Economic Instruments, Operational Arrangements)</td><td>No</td></tr>
</table>

Recognising the limitations of the WFD in fully addressing Water Scarcity and Drought (WS&D) issues in a more coherent way, the need for further developments was envisaged by the Member States, both at a political level and at technical level, aiming at acknowledging the relevance of WS&D and at fostering the analysis of measures to deal with WS&D within the implementation of the WFD (Afonso, 2007). The above referred concerns were reflected within the Common Implementation Strategy (CIS[2]) of the WFD, from the first stages to present developments, and advances have been made towards addressing WS&D issues more systematically in the EU policy arena. These advances are presented in detail in the following section.

[2] CIS is an informal structure set up in 2000 and led by the Commission which oversees the implementation of the Directive, and includes all Member States and candidate countries as well as key stakeholders.

2.2 EU Communications and Policy Initiatives related to WS&D

Within the EU Common Implementation Strategy (CIS) of the WFD, Water Scarcity and Drought (WS&D) was first addressed by the EU Water Directors (WD) in late 2003, who agreed to develop an initiative on WS&D issues. This decision came after one of the most widespread droughts, in 2003, when over 100 million people and a third of the EU territory were affected.

A Drafting Group led by France, Italy and Spain, was set up by the Water Directors to produce a Technical Document on drought events and water scarcity issues. In parallel, in 2004, a Mediterranean Working Group on WS&D (MED WS&D WG) was set up in the framework of the MED-EU Water Initiative/WFD Joint Process, in charge of producing a specific report on Mediterranean specificities and examples in the region. As a result of these activities, a Technical Document "Water Scarcity Management in the context of WFD" (MED JP WFD/EUWI, 2006b) and a Policy Summary (MED JP WFD/EUWI, 2006a) on WS&D were produced in June 2006, as well as a parallel Report on Mediterranean specificities and examples in the region (MED WS&D WG, 2007) in April 2007.

During the Environment Council of June 2006, a number of Member States requested to initiate a European Action on Water Scarcity & Droughts. Upon its agreement to analyse these issues, the Commission carried out two in-depth assessments of water scarcity and droughts in the European Union in 2006 and early 2007. An Expert Network on WS&D (which included representatives of Member States and stakeholders) has been mandated within the WFD CIS to support technical (e.g. development of indicators) and policy aspects (e.g. DMP guidelines), while consultation with stakeholders involved in WS&D issues was also launched. Following these assessments and activities, the Commission presented to the European Parliament and Council an initial set of policy options to address WS&D in the EU in a dedicated **Communication from the Commission to the European Parliament and the Council - Addressing the challenge of water scarcity and droughts in the European Union** (COM/2007/0414 final) published on July 18th, 2007 (EC, 2007a). The later constitutes the main EU Communication on the issue of WS&D. The Environmental Council of 30/10/2007 supported this Communication and specifically invited the Commission to review and further develop the WS&D policy by 2012. This review has been carried out on the basis of three Follow-up Reports (in 2008, 2009, and 2010 respectively), a series of targeted studies, as well as the participation of stakeholders, leading in a Policy Review in 2012. The review of the Strategy for WS&D has been integrated into the **EU Communication**

"Blueprint to safeguard European waters" (COM/2012/0673 final) published on 14/11/2012 (EC, 2012a), which further recognized that water quality and quantity are intimately related within the concept of good status. The "Blueprint" also recognised the need to put quantitative water management on a much more solid foundation (including identification of the ecological flow), to address the issue of over-allocation at the river basin scale, to develop water efficiency targets in water stressed areas, to reduce illegal abstraction, etc. In the post-2012 period a lot of emphasis has been placed on the assessment of water resources' availability in the EU river basins, and the development of detailed water balances (capturing the balance between availability and demand) at the appropriate spatio-temporal resolution, to support the identification of hot-spots and vulnerable areas, further linking them with economic elements (water accounts). In 2012 a Working Group on Water Accounts (WG WA) has been formed, as a follow-up of the EN WS&D, with the mandate to develop a Guidance Document on the application of water balances at the river basin and/or catchment scales for supporting the implementation of the WFD, and the sound and sustainable quantitative management of water resources. A detailed roadmap of the process that led to the 2007 Communication, as well as the post-Communication follow-up activities, is presented in Annex 1 of the dissertation.

On top of the above mentioned EC Communications COM/2007/0414 and COM/2012/0673, some additional EU Strategies' and Initiatives' policy objectives relate to WS&D issues, namely:

- The "EU Strategy on Adaptation to Climate Change" (EC, 2013) and the "White Paper Adapting to Climate Change" (EC, 2009) set an objective to build a solid knowledge base on the impact and consequences of climate change for the EU water resources as a basis for developing sound adaptation strategies in the field of water.
- The "GEOSS Water Strategy[3]" and the "Integrated Global Water Cycle Observation (IGWCO)[4]" set as objectives to develop widely available, sustained water cycle data sets and related information products, at both global and basin scales, tailored to the near- and long-term needs of stakeholders and end-users, to guide decisions on water cycle observations, and to promote strategies for the acquisition, processing and distribution of data products needed for effective management of the water resources.

[3] https://www.earthobservations.org/geoss_wa_tar.shtml

[4] https://www.earthobservations.org/wa_igwco.shtml

2.2.1 Policy options on the EC 2007 Communication on WS&D

As previously mentioned, the 2007 Communication on WS&D aims to address the increasing impacts of water scarcity and droughts in the EU, to ensure the long-term protection and the sustainability of available water resources, and to promote sustainable water uses. The specific objectives of the Communication are to enhance drought preparedness, mitigate all environmental and socio-economic impacts related to WS&D, and create the conditions for sustainable economic and social development across Europe in a context of climate change and increasing WS&D. The operational objectives relate to the identification of the most appropriate and cost-effective measures in order to efficiently address WS&D issues, and the consideration of possible priorities or a hierarchy to guide policy-making in the light of water availability at river basin level. To achieve these objectives the Communication identified a first set of 7 policy options, to be implemented on the basis on a combined/integrated approach, with a view to opening up a wide-ranging debate on how to adapt to WS&D. The details of the proposed policy options, along with the recommended "way forward" (EC, 2007a) and the progress made in relation to these policy recommendations (as assessed in the 2012 WS&D Policy Review) are presented in Annex 1 of the dissertation. The basic aspects are presented in Table 2.2 below.

Table 2.2: Policy options presented in the EC 2007 Communication on WS&D, and progress made towards their achievement.

Policy Option	Recommended way forward (EC, 2007a)	Progress made according to the 2012 WSD Policy Review (EC, 2012b)
1. Putting the right price tag on water	Put in place water tariffs, apply 'user pays' principle, achieve cost-recovery, introduce compulsory metering programmes in all sectors	Limited implementation of the cost-recovery and incentive pricing (water abstractions for agriculture is not priced in many EU regions)
2. Allocating water and water-related funding more efficiently	Improve land use planning, emphasis on sustainable agriculture, set up appropriate regulations and water saving measures to restore sustainable water balances, finance water efficiency	Land use adaptation is not common. Highly fragmented actions and technical measures are promoted instead of integrated land and water use planning. Illegal abstractions remain a challenge. Ecological flows are increasingly used in water allocation. Progress has been made in integrating water quantity aspects into the Common Agriculture Policy (CAP). An EC Communication (EC, 2011b) has been published to set efficient water supply and demand management as key actions of the ERDF and Cohesion Fund investments into

		water management in 2014-2020. Cost-benefit analysis has seldom been used to prioritize investments under the RBMP process.
3. Improving drought risk management	Develop Drought Risk Management Plans (DRMPs), identify methodologies for drought thresholds and drought mapping Develop an Observatory and an early warning system on droughts Optimise the use of the EU Solidarity Fund and European Mechanism for Civil Protection	The development of DMPs has progressed but their implementation and integration with RBMPs and other plans remains limited A prototype of the European Drought Observatory (EDO) has been developed. EU wide drought indicators are available on a preliminary basis for precipitation, soil moisture, vegetation response and a combined agricultural drought indicator. Limited progress has been made with the use of EU Solidarity Funds in the area of droughts.
4. Considering additional water supply infrastructures	Ensure that adverse effects related to any additional water supply infrastructure are taken into account in the environmental assessment Consider the changes expected as a consequence of climate change	In some MSs, additional water supply infrastructures have been developed before exploiting the full potential of water saving measures, thus in spite of the water hierarchy. The potential environmental impacts of new water supply infrastructure plans have not been systematically considered by MSs.
5. Fostering water efficient technologies and practices	Develop standards and legislation for water-using devices, include water efficiency criteria in performance standards for buildings, develop a new Directive for water performance of buildings, adopt performance indicators on the use of water working towards the possible certification, develop more water-friendly products, buildings, networks and practices.	Water efficiency gains have been achieved in irrigated agriculture, yet improving irrigation schedules and modernizing technologies can still provide significant water savings. Uncertainty remains how water saving at the field level is effectively translated into overall water saving at the farm and river basin level Efficiency margins are still significant in building, e.g. in relation to eco-design of taps and shower heads. In some cases, water distribution systems with low water efficiency (high leakage rates) can be at their optimal economic efficiency level.
6. Fostering the emergence of a water-saving culture in Europe	Launching an Alliance initiative on the efficient use of water, expand existing EU labelling schemes, include rules on water management in certification schemes, develop educational programmes, advisory services, targeted campaigns, etc.	MSs are implementing a broad spectrum of awareness raising activities, but other tools such as incentive pricing, financing mechanisms for water saving, eco-design water using appliances, etc. are not asufficiently present. Food and agricultural products: labeling schemes with a focus on the water footprint of a product, and schemes that are focused on encouraging good water stewardship are emerging
7. Improve knowledge and data collection	Develop a WS&D Information System throughout Europe, exploit the Global Monitoring for Environment and Security (GMES) services for the delivery of space-based data and monitoring tools, encourage research and technological activities,	EU wide coverage and long-time series of water quantity data are not yet available, therefore, the basic step of identifying water scarce river basins remains a challenge. Streamlined data on state and pressures, impacts and effectiveness of responses to address WS&D still need improvement. Progress towards the application of common WS&D indicators has been made under the

	disseminate research results on WS&D issues	WFD CIS. Water scarcity and water use efficiency research is scattered within the 6th and 7th Framework Programmes and synergies with MSs reasearch activities are missing.

The above assessment shows a diversity of inter-linked policy gaps in addressing WS&D in Europe and in relation to the 2007 EC Communication policy objectives. These range from conceptual, to information, to impelemntation gaps (EC, 2012b; Strosset et al., 2012).

- Conceptual gaps: Water scarcity and droughts are often not distinguished and indicators to illustrate the two phenomena have so far been insufficient. The understanding and identification of the cause-effect relationships between drivers, pressures, states and impacts is still weak, thus the solid indentification the most cost-effective measures for addressing WS&D is constrained.
- Information gaps: The ncessary data to allow for the asssessment of WS&D are often incomplete in terms of coverage, timeseries length, or parameters. Information on impacts is also limted, as well as informtation on the effectivensess of mitigation measures.
- Policy, governance and implementation gaps: most support actions and measures proposed by MS to address WS&D target pressures, state and impacts, and give priority to increase water supply measures. Measures that target key drivers of WS&D are limited. Measures such as metering, pricing/subsidies and restriction of water consumption are proposed in a few RBMPs only. Subsequently, a coherent set of such measures (e.g. land use policies, green infrastructure, alternative water supply options, etc.) need to be included in drought plans and/or RBMP. Responsibilities for and financing of the proposed measures is unclear. Adequate coordination with other planning processes and availability of financial resources is not satisfactory. Some EU countries already generate drought plans as part of their 'security of supply' procedures. These plans are often not based on catchments or specific rivers however. Indeed, this raises the question of whether the WFD, with its emphasis on planning for individual river basins, is a suitable vehicle for drought planning.

Currently, there is a tendency in the EU to move forward on a proactive risk management approach in order to increase the resilience and sustainability of the affected regions within the Member States. In addition, it is recognised that a number of actions must be further developed to improve water quantity management in the next

WFD RBMPs: defining and implementing ecological flows and targets for water efficiency, promoting economic incentives for efficient water use, guiding land use to respond to water scarcity, enhancing drought management in Europe, promoting resilience to climate change. At the EU level, there is a strong need to elaborate sound assessments of water resources that would accurately depict European diversity and possibly identify issues which call for targeted actions. The development of water resources assessment frameworks focusing on water balances or asset accounts (which use hydrological information), or incorporating additional elements and economic information related to water using concepts (physical supply and use accounts, hybrid and economic accounts), have been identified as a useful tool, not just for the purpose of identifying water stress in scarce areas, but for further understanding how efficiently water is used, what are possible territorial dependencies, and how water and the economy interact. The transition from crisis to risk management in Europe is challenging since governments and individuals are accustomed to a reactive approach, while little institutional capacity exists in many European countries for altering this behaviour. A fragmented approach towards WS&D management, country based and case specific, which may not necessarily be the most efficient, still prevails in Europe. The role of a EU wide coherent policy or strategy in this direction may be crucial, yet Member States are not favouring the establishment of an additional Drought Directive (on top of the WFD) which could severely increase compliance and reporting burdens, and seem to prefer non-mandatory EU legislation on this matter. The EC Communication of July 2007 is a useful first step in identifying new priorities, including opportunities to modernise technologies and processes to achieve much more water-efficient economies, yet as its implementation is based on a voluntary basis, MS action is not guaranteed, and their progress may be slow.

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CHAPTER 3 – METHODOLOGICAL APPROACH

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3 METHODOLOGICAL APPROACH

3.1 Background and rationale

Europe has experienced in the past 40 years drought episodes of various severities, duration and extend, with adverse impacts on both the environment and the society. A large scale comparison between the periods 1971-80 and 2001-11 per region (North, Central, Eastern, South EU) clearly shows that drought occurrence has significantly increased in the period 2001-11, not only in the South and Central EU, but also reaching now the North and Eastern EU (Kossida et al., 2012). Drought spells have been further recognized in the River Basin Management Plans, reported by the Member States under the Water Framework Directive (WFD), either as River Basin District wide phenomena or as local phenomena affecting parts of the entire basin in various cases. Policy actions have recently been intensified at the European and national levels in order to effectively implement drought management schemas that can support proactive risk management and consequently increase the resilience and sustainability of the affected regions. The development of such plans requires:

- the correct identification of the hazard itself,
- the proper assessment of the underlying vulnerabilities and risk,
- the identification of robust mitigation measures,
- the definition of relevant policy targets
- the elaboration of governance schemas that can support their implementation based on advanced instruments and institutions (mainstreaming)

In this direction, the current research proposes a set of operational methods and tools for supporting proactive drought risk planning and management in water stressed areas.

- **Identification and assessment of drought hazard, vulnerability and risk**

Assessing the components of drought vulnerability and risk is a complex multi-factor problem, still to be methodologically tackled. The underlying exposure to climatic stresses may be similar even in quite different conditions, yet the vulnerability and prevailing risk are a function of the socio-economic state, the current policy and institutional setting, the adaptive capacity of the affected area and population, and the response strategies adopted (Kossida et al., 2012). Although flood risk assessment has been elaborated under the EU Floods Directive, there is currently a lack of analytical frameworks for the definition and assessment of drought and water scarcity related risk at European level. This can partially be attributed to the inherent complexity of such phenomena which lie at the crossroads between physical and anthropogenic drivers and pressures, operating on many scales, and with a variety of impacts on many sectors. Vulnerabilities will be most apparent in certain regions and sectors, most notably in the Mediterranean (within the EU) and in agriculture. A proper risk management approach entails the correct identification of the current and future risk, at the appropriate spatial and temporal resolution, defined as the combined effect of the hazard and vulnerability, the latest being associated with the exposure, sensitivity, and resilience of the physical and socio-economic system. The identification, prioritization and quantification of all the components which constitute elements of the system' vulnerability to water scarcity and drought is highly challenging. While exposure relates to drivers and pressures, which are relatively easier to quantify, the sensitivity of the system is linked to the current and potential future impacts. The full identification, and especially the assessment of the sensitivity is thus very difficult and context specific. Finally, resilience needs to be considered in relation to a "total system value" where the adaptive measures applied are trade-offs of the systems' benefits and associated costs. Finding a representative methodology to analyze the cause-effect relations of all the above factors and their combined effect as the "total risk" is still weakly investigated. Nevertheless, the necessity to develop adequate tools in this context has been further highlighted in the 2007 EC Communication on Water Scarcity and Droughts (EC, 2007a) and the recently published 2012 EC Communication "A Blueprint to Safeguard Europe's Water Resources Blueprint" (EC, 2012a). Similarly, the High-level Meeting on National Drought Policy (HMNDP) in its Science Document on Best Practices on National Drought Management Policy (HMNDP, 2013c) has identified the need to develop and promote standard approaches and methodologies to assess drought vulnerability and risk at multiple spatial scales. These entail the understanding of the interplay of the natural processes and human activities that contribute to vulnerability and community resilience, the characterization of vulnerability, and the development of risk profiles reflecting the physical, social, economic and environmental pressures on a community (from global, regional, and local scales) in order to determine who and what is at risk and why. The integration of the vulnerability and risk information is considered necessary for the purpose of identifying proactive mitigation actions and measures that can lead to risk reduction. **Towards this direction, the current research proposes a methodological framework for defining Drought Risk Profiles** by assessing and mapping its main components: drought hazard and vulnerability. For this purpose operational indicators have been developed and proposed, easy to calculate and not too data demanding, so that practitioners and planners can elaborate relevant metrics to characterize and map the prevailing conditions as part of a drought management/action plan.

- **Identification of robust mitigation measures**

Drought and Water Scarcity impacts can be classified as direct or indirect, and affecting the economic, environmental and social welfare. Reduced crop and forest productivity, increased fire hazard, reduced water levels, increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat are a few examples of direct impacts (Wilhite et al., 2007). The European Commission recently determined that droughts in Europe have cost the economy 100 billion € over the last 30 years. Major impacts of drought on agriculture tend to be among the first to be reported, yet the energy sector, both for hydropower and power-plants which require cooling water, is also affected by water scarcity and drought. Impacts on ecosystems, river navigation, public water supply and other sectors carry significant economic, as well as social and environmental, costs. The 2010 European Council conclusions on water scarcity, drought and adaptation to climate change recognized the eminent problem. Considering that the likelihood of this situation is increasing due to climate change, the European Council urged Member States to elaborate water scarcity and drought management plans (WSDMPs). Developing appropriate programs of measures (PoMs) that facilitate adaptation to water scarcity and drought in Europe is challenging due to the diversity of economic, social, environmental conditions and wide range of situations where these are to be applied.

When considering adaptation measures to address water scarcity and drought issues, demand-side management has a great potential. There are, however, numerous challenges, regarding possible future conflicts between water users, environmentally harmful subsidies, controlling illegal abstractions, designing and enforcing tight accountability, measuring and water licensing mechanisms. These are gradually being discovered and addressed. In order for demand reduction adaptation to become a viable solution, cooperation is a key factor and requires appropriate institutional frameworks. This does not only require enforcement; public participation and awareness are even greater priorities in order to ensure that the threats to water resources are understood and appreciated. On the other hand, supply-side adaptation measures are already a common practice in arid regions and other areas affected by water scarcity and drought, and there is increased interest in extending these methods to other regions where the potential to harness waste, grey or rainwater is high. Yet, it is clear that they shouldn't be a priority and that we should resort to them only under specific circumstances. As demand management alternatives fit better with climate adaptation, work with nature instead of against it, and provide a lot of space for innovation, they must be prioritized in managing and mitigating water scarcity and drought, while increase supply measures should only be brought-in if the former cannot resolve the problems in hand. The High-level Meeting on National Drought Policy (HMNDP) in its Science Document on Best Practices on National Drought Management Policy (HMNDP, 2013c) has identified the need to enhance the implementation of drought preparedness and mitigation actions. Although no preference has been expressed between demand management and increase supply measures, it is clearly stated that response measures should reinforce the concept of risk management while promoting environmental stewardship. Intervention and incentives should be identified and provided to vulnerable sectors. **In this direction, the current research develops a methodology for identifying demand management interventions** which consider the vulnerability of the system and its sensitivity to future climatic and socio-economic conditions, looking at tradeoffs between costs and benefits across various sectors.

- **Definition and mainstreaming of relevant policy targets**

Having realized the high economic, social and environmental cost of inaction regarding water scarcity and drought, and the likely worsening under climate change, the importance of implementing concrete adaptation actions and internalizing them into development frameworks has been widely recognized (WMO and GWP, 2014; FAO, 2014; UNCCD, 2013; HMNDP, 2013b**Error! Bookmark not defined.**; EC, 2012a; EC, 2007a). Drought Management Plans continue to be developed and/or implemented throughout Europe, yet their mainstreaming is still weak. The cost implications, the possible tensions surrounding water resources, and the disentanglement of the suggested adaptation measures from the development plans and policies have been identified as bottlenecks to advancement and concrete implementation. However, commitment and prioritization by the European community is encouraging further developments, and progress is made towards adopting a more integrated risk-oriented approach as opposed to a reactive crisis management approach. The EC Communication addressing the challenges of water scarcity and drought (EC, 2007a) has clearly set as operational objectives the identification of the most appropriate and cost-effective measures in order to efficiently address WS&D issues, and the consideration of possible priorities or a hierarchy to guide policy-making in the light of water availability at river basin level. The High-level Meeting on National Drought Policy (HMNDP) in its Science Document on Best Practices on National Drought Management Policy (HMNDP, 2013c) has identified the need to understand effective decision-making in the context of drought risk management (what it is and how it can be improved), to conduct research on drought decision-making, to develop criteria to weigh the importance of vulnerability factors, to design/develop infrastructures that would support decisions regarding the selection of high-leverage mitigation actions at critical entry points, and to understand the cost of inaction and associated cost/benefit relationships. **In this direction, the current research proposes methodologies for prioritizing adaptation options through a cost-benefit optimization-based decision-making process, setting subsequent policy targets, and internalizing them in the development programs**. **Furthermore, it presents a roadmap to mainstreaming Drought Risk Management providing operational tools for the different steps of the process.**

3.2 Basic concepts of Drought Risk Management (DRM)

3.2.1 Basic Terminology

The following basic definitions are applicable in the context of the current research. They have been mainly extracted from the United Nations Office of Disaster Risk Reduction (UNODRR) UN/ISDR Terminology of Disaster Risk Reduction (http://www.unisdr.org/we/inform/terminology), and supplemented with terminology found in the UNDP, 2011; FAO, 2010; EEA WISE Glossary; African Development Bank, et al., 2004; Wilhite et al., 2014.

Water Scarcity: is defined as a situation of imbalance between supply and demand of freshwater in a specified domain resulting from a high rate of demand compared with available supply, under prevailing institutional arrangements and infrastructural conditions (FAO, 2010).

Water stress: occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.) (EEA WISE Glossary). Water stress is considered as a shorter and/or less permanent condition as compared to water scarcity.

Water balance: also referred to as water budget, it the balance between inputs and outputs of water into a system. A water balance can be obtained or calculated at various spatial and temporal scales depending on the level of analysis required in water management. The main inputs are precipitation, and external inflow (surface or groundwater), while the main outputs are evapotranspiration, outflow (river discharge or groundwater seepage), and abstractions. Water balances can be simplified or more complex (including additional components, such as returned water, etc.) depending on the scale and requirements of the analysis.

Unmet Demand: also referred to as water shortage, is the portion of a water user's demand that is not covered by the available water supply, and can be attributed to physical (i.e. availability of water resources) or technical factors (e.g. flow restrictions).

Drought Hazard: based upon its atmospheric and hydrological phenomena, drought is categorized as a natural, or more specifically a hydro-meteorological, hazard. It is a natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UN/ISDR 2009). Drought hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. They are creeping phenomena that develops over time, and thus its impacts are diffuse and spread slowly, in contrast to other rapid onset natural hazards, such as floods. They also tend to have wide-reaching impacts over a large geographical area.

Drought Impact: is the adverse effect of a drought hazard event on the society, economy and the environment, either direct or indirect. The likely impact of drought would increase as (a) the hazard level (measured, for example, by the number of persons exposed and/or frequency/severity of drought) is higher; and (b) the vulnerability of a community (or sector or system) is greater (UNDP, 2011).

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Vulnerability is an encompassing composite term. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure (UN/ISDR).

Drought risk: refers to the potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time as a result of a drought hazard (adopted by the UN/ISDR definition of disaster risk). It reflects the combination of the probability of an event and its negative consequences. The level of drought disaster risk is often measured by the combination of (a) the degree of exposure to a drought hazard and (b) the level of vulnerability that a community (sector or system) faces (African Development Bank, et al., 2004). This concept is expressed in the following formula: Risk = Hazard x Vulnerability. According to this principle, a large number of individuals subjected to exposure to a moderate drought hazard could be considered at the same risk level as a smaller number of people who live with a higher frequency and/or severity of drought hazards (UNDP, 2011).

Resilience: is generally defined as the ability of a system, community or society that is potentially exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and effective manner, including through the preservation and restoration of its essential basic structures and functions (UN/ISDR). This ability is determined by the degree to which the social system is capable of increasing its capacity for learning from past disasters, and translating the lessons into improved future protection and risk reduction measures (African Development Bank, et al., 2004). Resilience is the opposite of vulnerability; the higher the level of resilience of a community, the lower the degree of vulnerability. The drought risk of a given community is decreased when resilience is increased (UNDP, 2011)

Adaptation: the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. This definition addresses the concerns of climate change and is sourced from the secretariat of the United Nations Framework Convention on Climate Change (UNFCCC). The broader concept of adaptation also applies to non-climatic factors such as soil erosion or surface subsidence. Adaptation can occur in autonomous fashion, for example through market changes, or as a result of intentional adaptation policies and plans. Many disaster risk reduction measures can directly contribute to better adaptation (UN/ISDR).

Drought mitigation: is the lessening or limitation of the adverse impacts of droughts. Mitigation measures encompass engineering techniques as well as improved policies and public awareness (UN/ISDR).

Drought preparedness: refers to the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current drought events or conditions (UN/ISDR).

Drought recovery: refers to the restoration and improvement where appropriate, of facilities, livelihoods and production conditions of drought-affected communities, including efforts to reduce drought risk factors (UN/ISDR)

Drought response: is the provision of emergency services and public assistance during or immediately after a drought in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected. It can be of an immediate, short-term, or protracted duration (UN/ISDR).

Drought risk management: the systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of drought hazards and the possibility of disaster. Drought risk management aims to avoid, lessen or transfer the adverse effects of drought through activities and measures for prevention, mitigation and preparedness (adopted from the UN/ISDR definition for disaster risk management)

Drought crisis management: is a reactive approach to alleviate the drought hazard impact, focusing on relief measures in the form of emergency assistance, providing money or other specific types of assistance to the drought victims. This reactive approach only addresses the symptoms and does not act as a driver to change behaviors and/or management practices (Wilhite et al., 2014).

3.2.2 Traditional and emerging paradigms in Drought Risk Management

The traditional approach to DRM is reactive, and focused on crisis management. The response actions target to alleviate the impacts, are often untimely, and lack coordination and integral planning (UNCCD, 2013). Crisis management only addresses the symptoms of drought, as they manifest themselves in the direct or indirect impacts, and is seriously flawed from the perspective of vulnerability reduction (Wilhite et al., 2014). As a result, the risk to future events is not reduced, while the resilience of the affected communities is not enhanced. Risk management, on the other hand, is focused on identifying vulnerabilities and addresses the prevailing risks through systematically implementing mitigation and adaptation measures that will lessen the risk and impacts of future drought events. Figure 3.1 illustrates the main features of crisis and risk management.

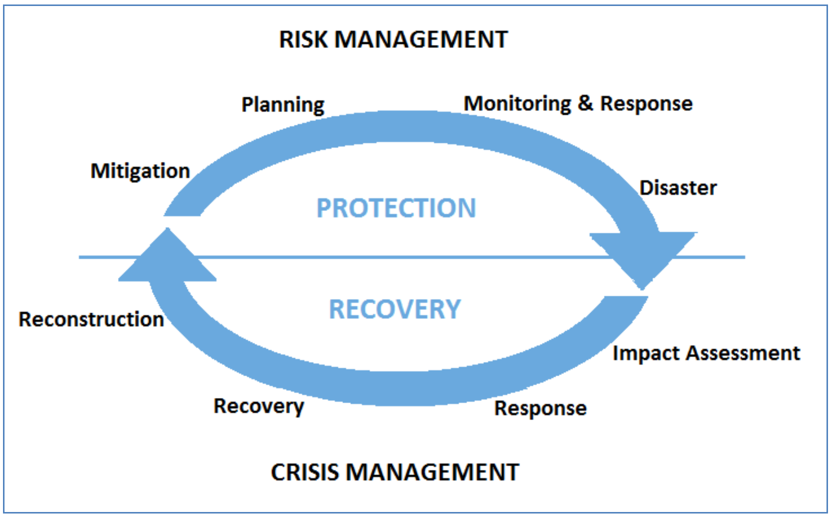

Figure 3.1: Cycle of disaster management

(Source: National Drought Mitigation Center, University of Nebraska-Lincoln)

Historically, limited focus has been paid on proactive risk management, and more specifically on preparedness, mitigation or prediction, early warning actions, and the development of risk-based national drought management policies that could avoid or reduce future impacts (WMO and GWP, 2014). The main drought management activities have been focused on immediate safety net and relief measures or short-term response measures such as (UNDP, 2012): supplying food aid and other non-food items to affected communities, providing emergency livestock purchases and supplementary livestock feeding (fodder, forage, etc.), providing seed distribution and low-interest agriculture loans, facilitating borehole rehabilitation and water-trucking, setting-up emergency assistance programmes and establishing a local coordinating bodies, developing water use guidelines and emergency water allocation strategies, imposing water bans, quotas and water supply restriction, increasing local awareness, increasing local drought monitoring capacity and infrastructure, providing subsidies for drought-affected population, etc.

Recognizing the need to cope with drought in a sustainable manner, planners and policy makers are now moving towards proactive risk management, effective impact assessment procedures, and preparedness plans, in an attempt to increase the coping capacities and resilience of the affected communities, while minimizing the severity and extent of the adverse impacts of drought. Proactive drought risk management focuses on preparedness and coordinated measures that should be planned proactively and implemented before, during and after droughts. These measures can be identified by carrying out a drought planning process and implemented through the resulting drought plan (FAO, 2014). In this context, the development of national or regional drought management plans (DMPs) is becoming more and more widespread (Sivakumar et al, 2011). For example, in the US, 47 of the 50 states have drought plans, and 11 of these states are placing an ever-increasing emphasis on mitigation as a primary means of reducing societal vulnerability (NDMC, 2013).

Several drought planning methodologies have been developed to provide guidance on developing national or and regional DMPs (FAO/NDMC, 2008; WSDEN, 2008; Iglesias et al., 2007; and Wilhite et al., 2005). One of the tools that has been instrumental in providing guidance in the development of drought preparedness plans in the United States is the "10-step drought planning process" originally proposed in 1991 (Wilhite, 1991) and subsequently modified to place emphasis on mitigation in the planning process (Wilhite et al., 2000; Wilhite et al., 2005). It provides a set of guidelines that outline the key elements of a drought plan, and a process through which they can be adapted to any level of government (i.e., community, river basin, state, national) or geographical setting. These steps provide a "checklist" to be considered as part of the planning process:

Step 1: Appoint a drought task force

Step 2: State the purpose and objectives of the drought mitigation plan

Step3: Seek stakeholder participation and resolve conflict

Step 4: Inventory resources and identify groups at risk

Step 5: Prepare and write drought plan

Step6: Identify research needs and fill institutional gaps

Step 7: Integrate science and policy

Step 8: Publicize the drought mitigation plan, build public

Step 9: Develop education programs

Step 10: Evaluate and revise drought mitigation plan

In brief, steps 1–4 focus on organizing a task-force, bringing together the relevant stakeholders, clarifying the purpose and objectives of the plan, identifying the target groups and available resources and data. Step 5 describes the process of developing a dynamic DMP. Steps 6 and 7 identify research needs and coordination mechanisms between scientists and policy makers. Finally, steps 8-10 focus on the dissemination, awareness rising through education, and testing and subsequent revisions of the plan.

Regardless of the different methodologies, it is widely accepted that the development of a DMP requires the following components: (a) a monitoring and early warning system; (b) vulnerability and impacts assessment; (c) mitigation and response actions; (d) involvement of stakeholders in the designing process through participatory approaches. While DMPs provide the basis for a paradigm shift, they are only one building block in vulnerability reduction, as they constitute the instruments through which a national drought policy can be executed and/or downscaled. They need to be intrinsically linked to the national drought policy, and most importantly to the national development and funding frameworks, so that their suggested measures can be internalized into a high-level trans-disciplinary planning. Toward this direction, the UNDP recently proposed the concept of "mainstreaming drought risk management" (UNDP, 2011) which moves proactive risk management one step further, by linking the related measures to existing policies and institutions, and internalizing risk management plans into the development national, sectoral and local programs and frameworks. This approach can boost their implementation and sustainability.

3.3 Overall methodological approach

The overall objective of the current research is to **develop operational methods and tools for supporting drought risk management in water stressed areas**. It aims at linking science to the decision and policy-making process and providing supportive engineering tools. The overall methodology is based on the basic concepts of mainstreaming (UNDP, 2011) and develops a set of relevant tools for proactive drought risk management and planning, implementing a step-wise approach that integrates physical and anthropogenic drivers and pressures, impacts and response.

Mainstreaming is defined as "a process of change, whereby certain issues are integrated into planning and decision-making processes and these issues continue to be part of the agenda in subsequent planning, implementation and revision" (UNDP, 2008). Mainstreaming helps achieve multiple goals, i.e., development of cross-sectoral and mutually reinforcing policies, and leveraging of national and international funding and other resources. In the context of Drought Risk Management (DRM), mainstreaming clearly relates to proactive risk management, as it helps addressing drought issues not simply as a natural phenomenon but as a more complex development issue. It supports the internalization of drought risk throughout the planning, funding and implementation stages of any development framework, and further ensures that sectoral policies do not counter their intended purposes of drought mitigation and preparedness-related efforts (UNDP, 2011). It further sets the cornerstones towards the identification and development of the proper enabling environment and institutional setting that can strengthen the adaptive capacity of the affective communities in a sustainable way.

To achieve mainstreaming, and hence proactive risk management, a set of steps must be coherently followed. These steps span from science to policy activities, while interfacing between them holds an important role so that the developed scientific and policy tools are tailored to the local specificities and can directly support future developments enhancing the local adaptive capacity. The methodology developed in the framework of the current research identifies and builds around four basic steps, while for each step elaborated methods and tools are provided to support its operational implementation. The latter is very important to highlight: the prevailing innovation of the current methodology is not just about proposing a set of steps for proactive drought risk management, but in elaborating methods and tools which can support the actual operational implementation of these steps, and which are adaptable under different contexts. Across these four steps, the proposed tools cover all components which need to be accounted for in drought risk management, spanning from the drought hazard evaluation, to the assessment of water resources availability and demands across economic sectors, to mapping of water scarcity vulnerability and developing drought risk profiles, and finally leading to the design of optimal mitigation measures, linking them to the decision-making process in order to set policy targets, and internalizing them into development programming frameworks.

The four proposed steps in proactive drought risk management, to be followed in a sequential order, are presented below (Figure 3.2) and are harmonized (to a good extent) with the UNDP proposed steps (Figure 3.3) in mainstreaming DRM.

- Step 1: Definition and development of a Drought Risk Profile
- Step 2: Identify DRM options: design and simulation of mitigation measures
- Step 3: Prioritize DRM options: Optimization and Decision-making
- Step 4: Internalize DRM: Definition of policy targets and Implementation

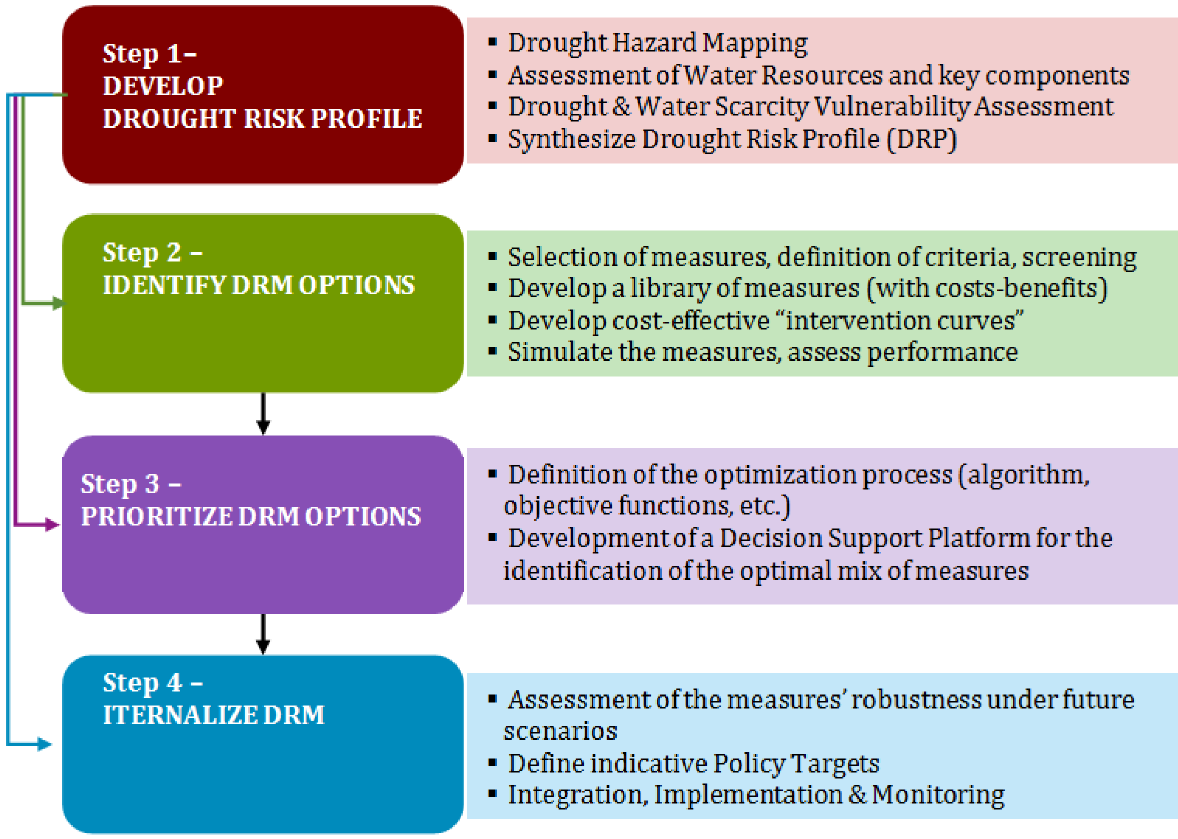

Figure 3.2: Main steps and actions in mainstreaming Drought Risk Management

Although the above proposed steps are well-harmonised with the UNDP identified ones (Figure 3.3), there are some differences. The core remains the same, i.e. definition of a drought risk profile, identification and prioritization of options, but some of the UNDP steps are considered here as ancillary elements and supporting tools rather than concrete individual steps. For example, setting-up a stakeholders' coordination mechanism is considered as an activity/tool supporting the definition of Drought Risk Profiles and DRM Internalization rather than a stand-alone step. Similarly, measuring the impact of DRM mainstreaming is also seen as an element of the successful implementation of step 4 (Internalizing DRM).

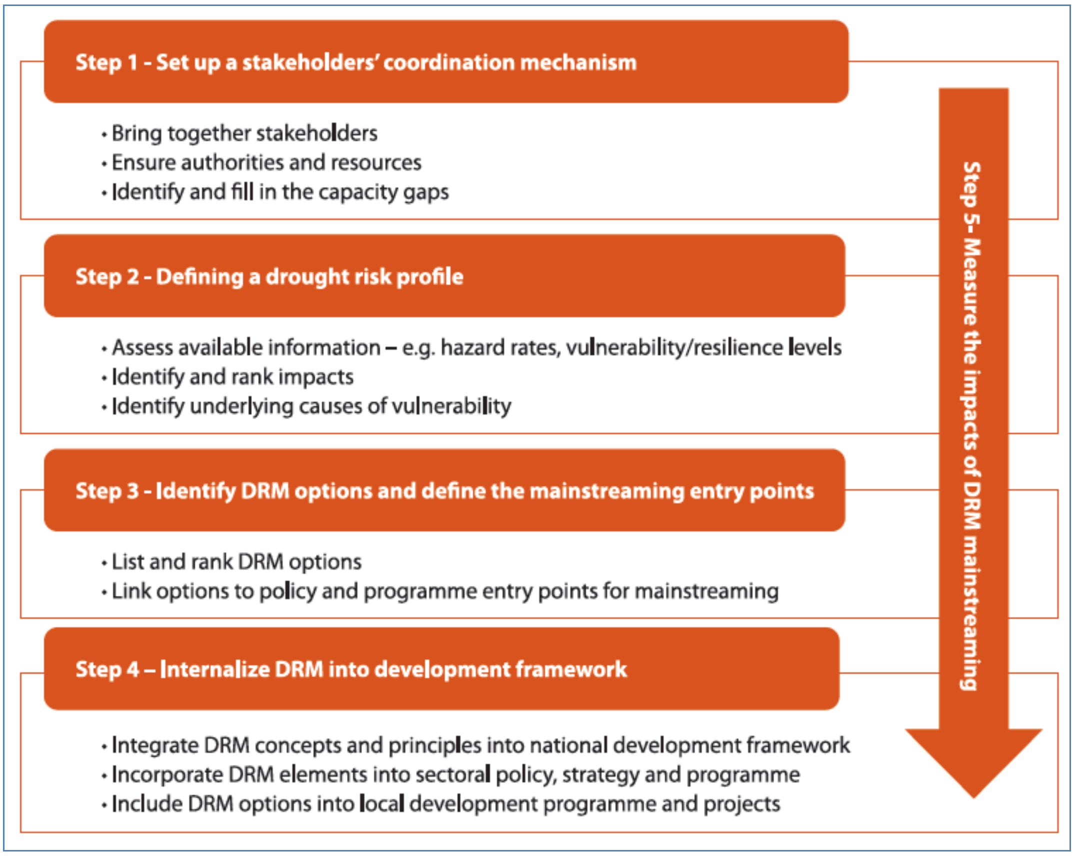

Figure 3.3: UNDP proposed steps in mainstreaming Drought Risk Management

To implement the four proposed steps a set of tools is developed. The details of each step, and the proposed tools to support its implementation, are presented in the following sections. Figure 3.4 presents an overview and the interlinkages among steps and supporting tools and methodologies.

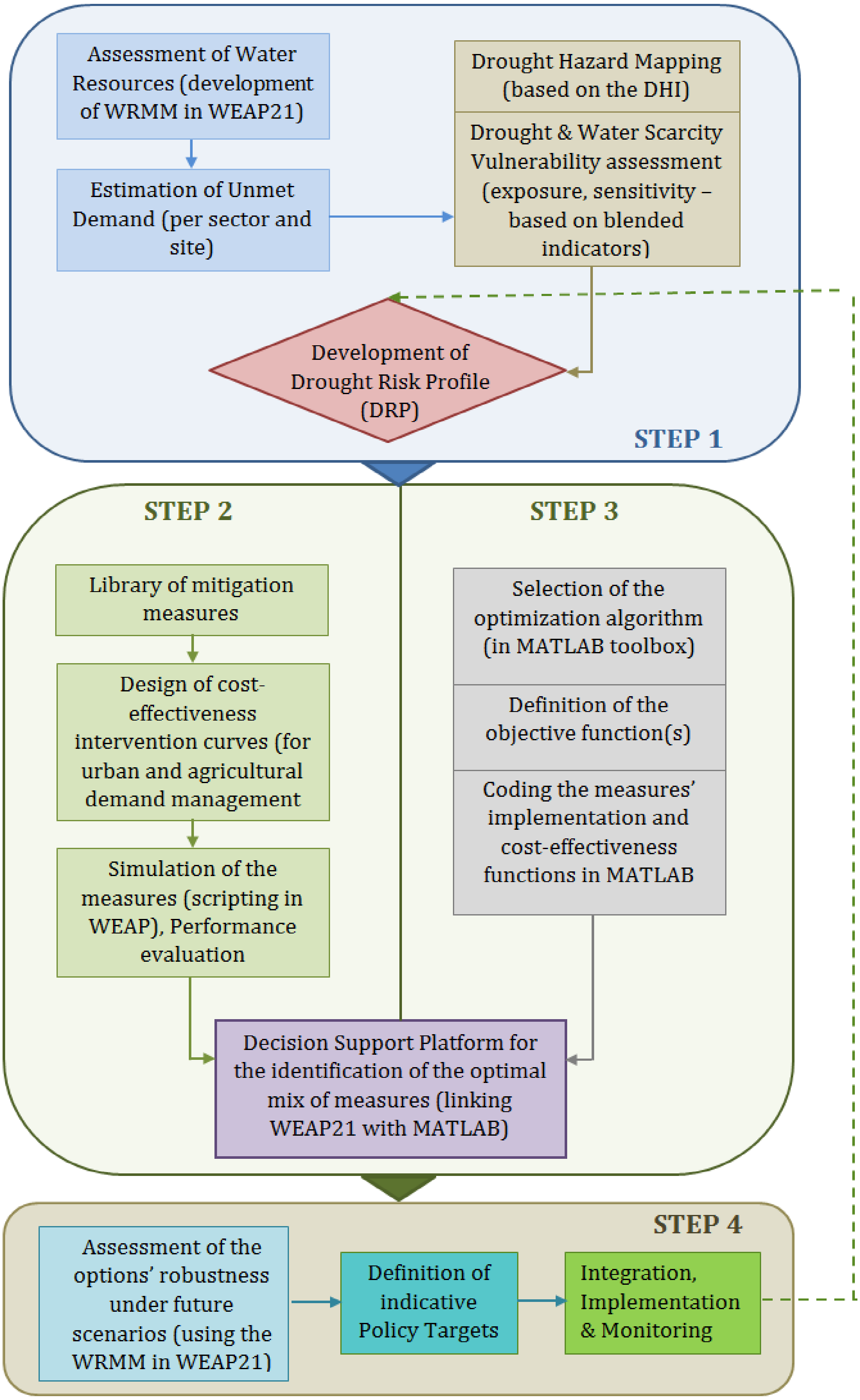

Figure 3.4: Overview of the methodological approach: steps and associated methods and tools for DRM.

Step 1: Definition and development of a Drought Risk Profile

The definition and development of Drought Risk Profiles (DRP) is considered as the first step in Drought Risk Management. Drought risk profiling aims to show the combined effect of the physical (i.e. climate) and socio-economic pressures on a specified region, community, etc. In this step, a methodology to profile drought risk is developed, involving (Figure 3.5):

(a) the analysis and mapping of the climatic hazard,

(b) the analysis of vulnerability/resilience factors, using various indicators tailored to the context and specificities of the region under investigation. In some cases detailed Water Resources Management Models need to be used to assess the water resources, estimate key vulnerability parameters (e.g. unmet demand) and subsequently feed them in the vulnerability assessment.

(c) the combination/integration of the above two.

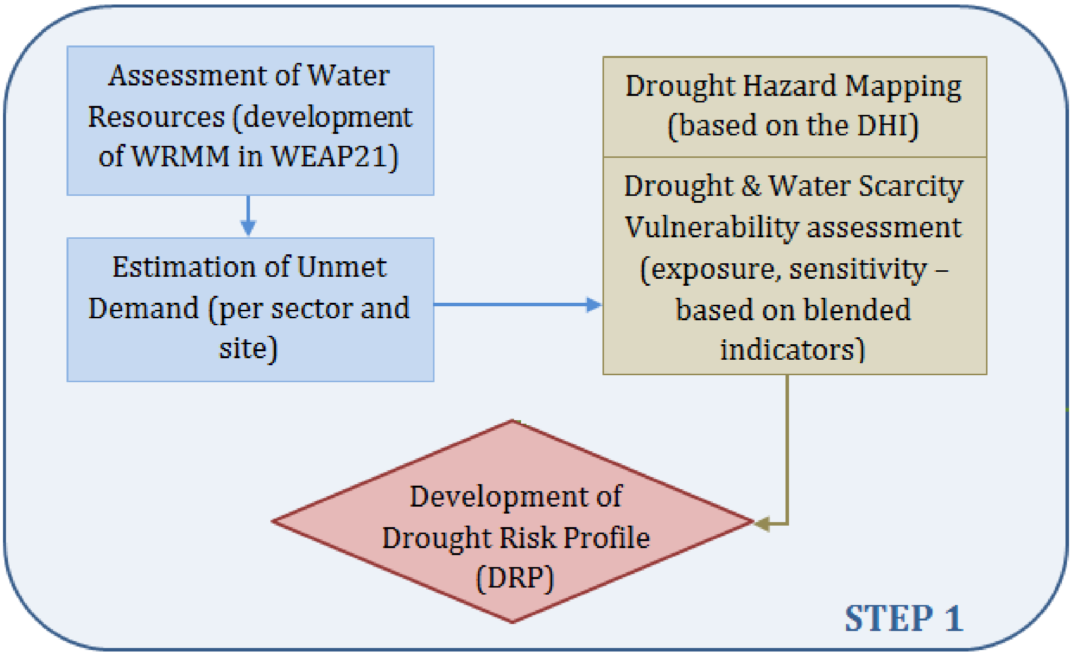

Figure 3.5: Overview of the Step 1 methodology

To analyze the climatic hazard a new indicator has been developed, the so-called Drought Hazard Index (DHI). This indicator can be calculated on the basis of monthly precipitation data, derived from rain gauges within the region of interest, and captures all the drought hazard components: recurrence, severity, magnitude, duration. The details of the DHI and the methodology for processing the monthly precipitation data and deriving four sub-indicators which are effectively blended into the DHI are presented in Chapter 4. More specifically, the 4 sub-indicators which feed the DHI have been defined to reflect: the number of drought events within the reference period (metric of recurrence), the number of drought events with a duration larger than 24 months (metric of severity), the maximum intensity of the observed drought episodes (metric of magnitude), the maximum duration (metric of duration). On the basis of the DHI, relevant Drought Hazard maps can be produced. The DHI has been tested in two areas, namely the Ali-Efenti catchment in Greece (Kossida and Mimikou 2015, Kossida and Mimikou 2013a, Kossida and Mimikou, 2013b), and the Tiber Basin in Italy (Maccioni et al., 2014), and has been validated against hydrological impacts (river streamflow and spring discharge observations). The DHI is an easily reproducible indicator, based on commonly available precipitation timeseries, and flexible enough to be computed for multiple timescales relevant to the drought analysis. It is spatially consistent allowing for comparisons between different areas. It can be calculated for different time periods, permitting thus the assessment of the evolution of drought hazard over time and the detection of trends, while its historic context is suitable for decision making. Finally, the DHI allows for easy integration with additional relevant indicators of environmental or socio-economic context, necessary for the analysis of relevant vulnerabilities and risk.

To analyze vulnerability to water scarcity and drought, a conceptual schema of the components which shape vulnerability has been identified. These are categorized under exposure and sensitivity, potential impacts and adaptive capacity (Figure 3.5). The exposure and sensitivity parameters relate to the pressures and state of the exposed to the hazard system, while the adaptive capacity relates to the response measures in a common DPSIR framework (drivers-pressures-state-impact-response). In the current methodology, the parameters that are proposed to define drought vulnerability are associated with the former (exposure, sensitivity), while the later (response) are used in subsequent steps of the methodology as means to increase the ability to mitigate and respond and thus reduce the associated risk. In the context of water stressed areas, the current methodology identifies that the balance between availability and demand is a key component of vulnerability, necessary to be accounted for and integrated in any drought risk profile. Unmet demand, which is associated with different drivers (be it physical or anthropogenic), and water supply reliability, are commonly the limiting factors and main pressures leading to increased vulnerability conditions in periods of drought. Yet, these data are not always available at an adequate disaggregation level (spatial, temporal, or sector-specific), and thus estimates and proxies must be used instead. In this context, the current research identifies that the development of adequate modelling frameworks which can capture and represent the salient features of the hydrological cycle on one side, and water users' needs on the other side (especially in data scarce cases) is a valuable tool in identifying and mapping these vulnerability components. The Water Evaluation and Planning System (WEAP21[1]) is investigated here for its capacity and flexibility as a modelling tool in delivering estimates of these components in cases of limited available primary data, and tested in the Ali-Efenti catchment in Greece.

[1] http://www.weap21.org/

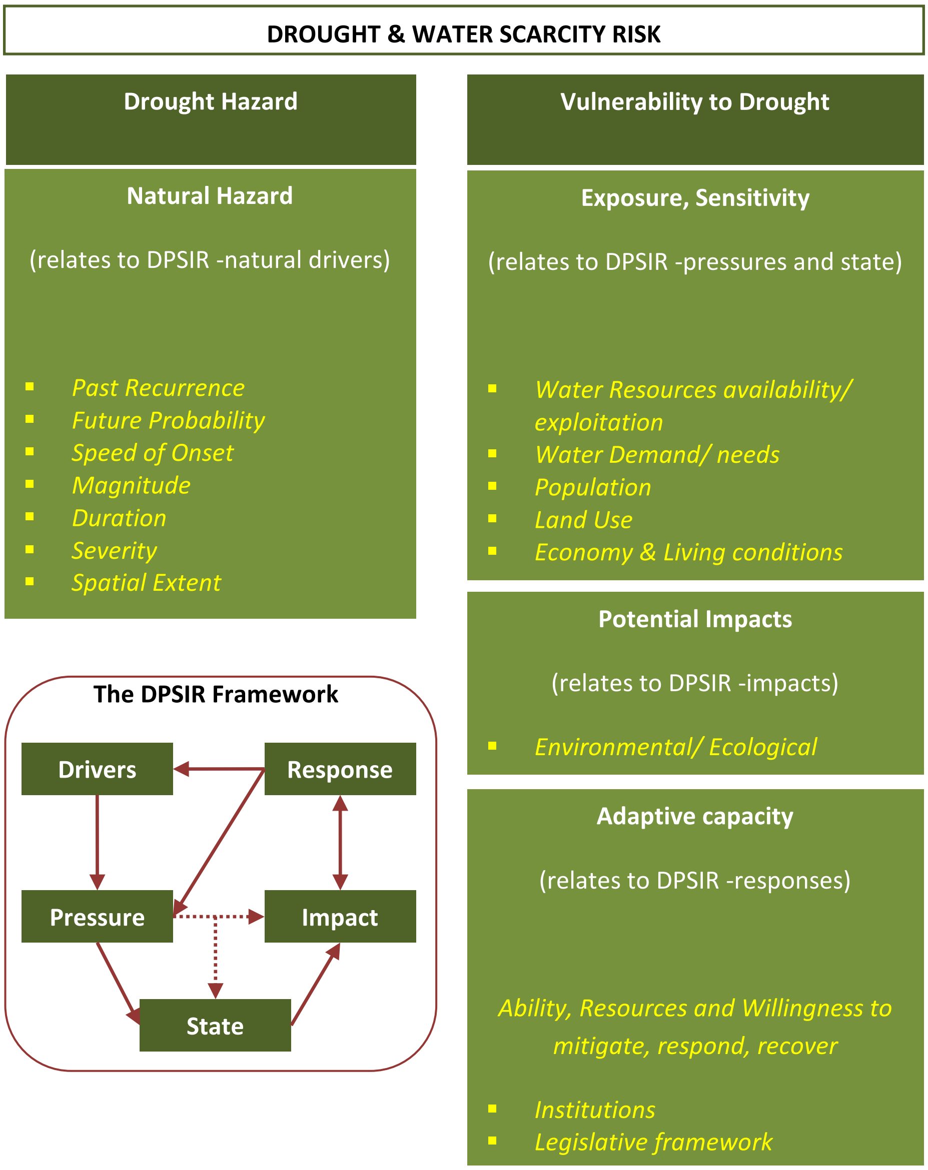

Figure 3.6: Conceptual schema of the components of drought and water scarcity risk, and their relation to the DPSIR.
(adopted from Wood, 2011; Kossida et al., 2012a).

To synthesise a Drought Risk Profile (DRP) the production of disaggregated risk maps is proposed in the current methodology as a meaningful tool. The production of the maps is based on the spatial and temporal aggregation of the hazard and vulnerability indicators mentioned previously. DRP maps allow for the quick identification of hot-spots, and have thus a good operational value. They also have the flexibility to be expanded or reduced upon the policy-makers' desire to include/exclude vulnerability components. The following process leads to the production of the DRP and is presented in detail in Chapter 4. The methodology is also tested in the Ali-Efenti basin in Greece.

1. Selection of the appropriate temporal and spatial scale of analysis.
2. Analysis of the meteorological drought episodes using the DHI, and production (on the basis of the DHI interpolation) of drought hazard maps for different time periods.
3. Analysis of the components of physical and socio-economic vulnerability in the region of interest (engaging also stakeholders) and selection of the key indicators which shape vulnerability (within the constraints imposed by data availability).
4. Set-up (including calibration and validation) of appropriate disaggregated modelling frameworks and tools (e.g. WEAP21) to obtain estimates of unmet demand and water supply reliability per user in case these data are not readily available.
5. Establish links to feed the above modelled/estimated parameters into the matrix of vulnerability indicators at the appropriate spatial and temporal scales.
6. Blend the vulnerability indicators into a Drought Vulnerability Index (DVI), using relevant scoring criteria and weights based on an Analytical Hierarch process (AHP), and produce vulnerability maps.
7. Overlay the hazard and vulnerability maps (in a GIS environment) to obtain Drought Risk Profiles and associated maps.

Step 2: Identify DRM options: design and simulation of mitigation measures

In this step, a generic methodology for designing demand management options (i.e. interventions and measures covering management, technological and economic aspects) for the urban and agricultural sectors is developed. The demand management options target in reducing the unmet demand and increasing the water supply reliability, which are main component of the vulnerability profile as discussed in the previous step 2. Thus, they target to reduce the associated drought risk. The methodology (presented in detail in Chapter 5) incorporates the development of cost-effective “intervention curves”, based on a bundle of measures which promote water saving and efficiency gains, able to be adjusted under different regional context and expert input from stakeholders. The bundle of measures investigated could benchmark the effect on an “alternative policy” focused on demand reduction across the main economic sectors. The focus here has been placed on demand reduction measures since the recent assessment of the Water Framework Directive River Basin Management Plans (WFD RBMPs) showed that water supply measures are significantly stronger reflected in the screened set of plans (about 30-40% of RBMPs) than restrictions of pressures (e.g. new water-demanding urban or agricultural developments) or measures to ensure the achievement of the environmental WFD objectives under water scarcity and drought conditions (EC, 2012b). The following methodology has been defined in order to develop "intervention curves" (Figure 3.7):

1. Selection of the initial list of measures and priority sectors (in this case urban, agriculture), in consultation with local stakeholders.
2. Definition of criteria for the initial screening of the measures: technical feasibility, water saving potential, potential risks, costs (investment & maintenance), social acceptability, additional benefits (energy savings, water bill reduction, reduction of wastewater generation, increased yields, water supply security), compatibility with existing policies and development plans. These criteria enable the initial screening and elimination of "less suitable" measures, and shape the options of the demand reduction policy.
3. Collection of information on expected water savings and costs, and development of a library of the selected measures (including the potential water savings and costs for each measure).
4. Development of cost-effective "intervention curves" for the urban and agricultural sectors, on the basis of the characteristics of the selected measures, and a cost-benefit optimisation. An optimization algorithm has been built and applied in Matlab in order to optimize the intervention measures' selection. The objective here was to maximize water saving while minimizing the total cost (investment and operation/maintenance) by allowing a mix of measures under each sector (i.e. urban, agriculture). This procedure results in different mixes of measures for each sector that can achieve various percentages of demand reduction under specific costs, as mapped by the results of the optimization process.
5. Test/simulate the impact of the final mix of measures against specific criteria on a physical-based water management model in order to assess their true potential under specific conditions and constraints (in this study the WEAP21 modelling environment has been tested).

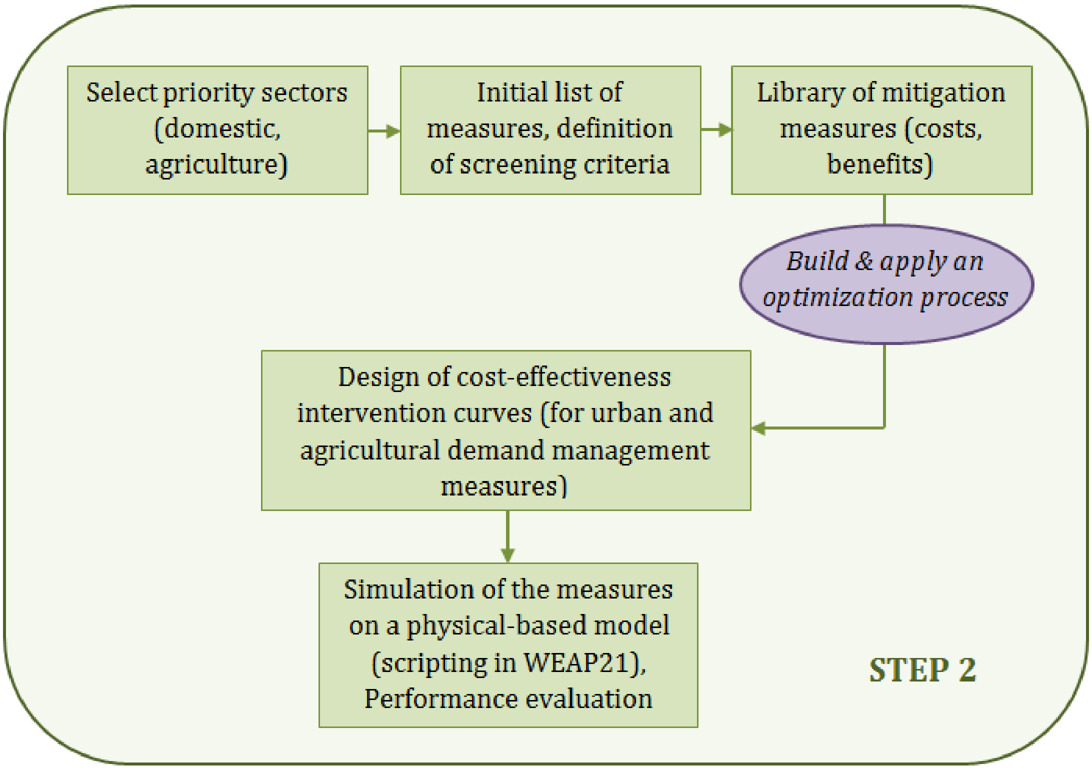

Figure 3.7: Overview of the Step 2 methodology

The selected demand management measures focus on water saving in the urban sector, as well as on leakage reduction, improved irrigation practices and crop changes in the agricultural sector, as presented in Table 3.1 below. For each measure an extended review has been carried out in order to define the potential water saving and associated cost of the measure in Annual Equivalent Cost (AEC).

Table 3.1: Selected measures used for simulating the proposed demand reduction policy.

Sectors	Measures for water saving and/or improved irrigation efficiency
Urban	1. Low water using appliances (low flow taps and shower heads, dual toilet flushes, efficient washing machines, dishwashers, etc.) 2. Rainwater Harvesting (RWH) 3. Domestic Greywater Reuse (GWR)
Agriculture	1. Replacement of open canals with closed pipes 2. Change of irrigation methods ▪ Switch to drip irrigation and/or sprinklers from furrow irrigation systems

	▪ Apply deficit irrigation ▪ Precision agriculture 3. Change of crops (% of the existing ones to new crops)

- **The urban intervention curve**

For the design of the urban intervention curve, 7 water saving measures have been considered: istallation of dual flush toilets (1), retrofitting of low flow taps (2) and showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. These measures have been clustred under two tiers: Tier 1 measures comprise of dual flash toilets, low flow taps and showerheads, efficient washing machines and dishwashers, while tier 2 measures additionally include rainwater harvesting and domestic greywater reuse systems. To estimate the potential water saving of each measure the different household microcomponents have been considered, along with their share on the total household consumption, as well as the reported performance (% water saving, targeted microcomponent) of each measure. The AEC of each measure (including the investment, operational and maintenance costs) and its useful life have also been researched and defined. These data have been stored in the library of measures. Based on these calculations, the total potential water saving if applying all tier 1 measures (i.e. creating a "water efficient house") is estimated to reach 46.5% of the total household consumption (or 16.6% per capita assuming an average household size of 2.8 persons) (Table 3.2), with a respective total cost of 1,550 € per household (or 554 € per capita). The application of additional tier 2 measures (rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier 1 measures in a "water efficient" house delivers an additional 16.2% saving per husehold with an additional cost of 6,000 €. Thus, the total domestic water saving potential sums up to 62.7% per household (or 22.4% per capita), with a respective total cost of 7,550 € per household (or 2,696 € per capita). In reality, since the rainwater harvesting and greywater reuse are expensive measures it is expected that a household would opt them after the tier 1 measures have been pursued. This assumption is considered in the calculations when building the urban intervention curve. For example, the potential influent to the GWR system (which originates from the showers/ baths and washing machines of the "water efficient house") has been properly adjusted to account for the already achieved water saving of the tier 1 measures, and thus the influent potential volume has been accordingly decreased.

In order to design the optimum urban water cost-effective curve, the current methdodology proposes to run an optimisation process, dividing the total mumber of households in the area of interest into clusters, where different set of measures are applied in order to be able to capture a greater variability in the distributed solutions and their degree of penetration. The objective function of the optimization is to maximize water savings while minimizing the AEC. The Matlab Global Optimization toolbox was used here, which incorporates NSGA-II, and a script has been developed for that purpose. The total number of households was divided into 5 clusters, with each cluster having 7 decision variables (i.e. the 7 water saving measures discussed above). The results of the optimization (Pareto front) are presented in Figure 3.8. Each point on the pareto curve represent a solution which includes a specific mix of measures (and its corresponding degree of penetration for each of those measures).

Table 3.2: Cost-effectiveness of the domestic water saving measures used in the design of the urban "intervention curve".

	Water Saving Measure	Performance (% water saving)	HH Micro-component targeted	HH Micro-component water consumption share (%)	Unit Cost €	AEC €	Expected water saving as % of total HH consumption
Tier #1	Dual Flush Toilet	40 %	WC	25 %	170 €	32 €	10 %
	Showerheads replacement (1 item)	60 %	Bath + Shower	34 %	30 €	11 €	20.4 %
	Low flow taps (2 items)	50 %	Faucets	13 %	50 €	19 €	6.5 %
	Efficient Washing machine	40 %	Washing Machine	14 %	600 €	111 €	5.6 %
	Dishwasher	50 %	Dishwasher	8 %	700 €	130 €	4 %
			Outdoor use (garden, car washing)	6%			
Tier #1 TOTAL				100 %	1,550 €	303 €	46.5 %
Tier #2	Rainwater Harvesting *(the effluent goes to: WC, washing machine, outdoor use of the tier #1*	40 % (accounting the rainy months)	WC, washing machine, outdoors	29 %	2,500 €	356 €	11.6 %

	"water efficient" house)						
	Greywater Reuse *(the influent originates from shower, bath and washing machines , i.e. the 22% of the tier #1 "water efficient house", and the effluent goes to WC and outdoor use)*	22 % *(potential influent from shower, bath and washing machine of the "water efficient" house)*	WC , outdoors	21 % (15% WC + 6% outdoors)	3,500 €	498 €	4.6 %
Tier #2 TOTAL				44 %	6,000 €	854 €	16.2 %
GRAND TOTAL					**7,550 €**	**1,158 €**	**62.7 %**

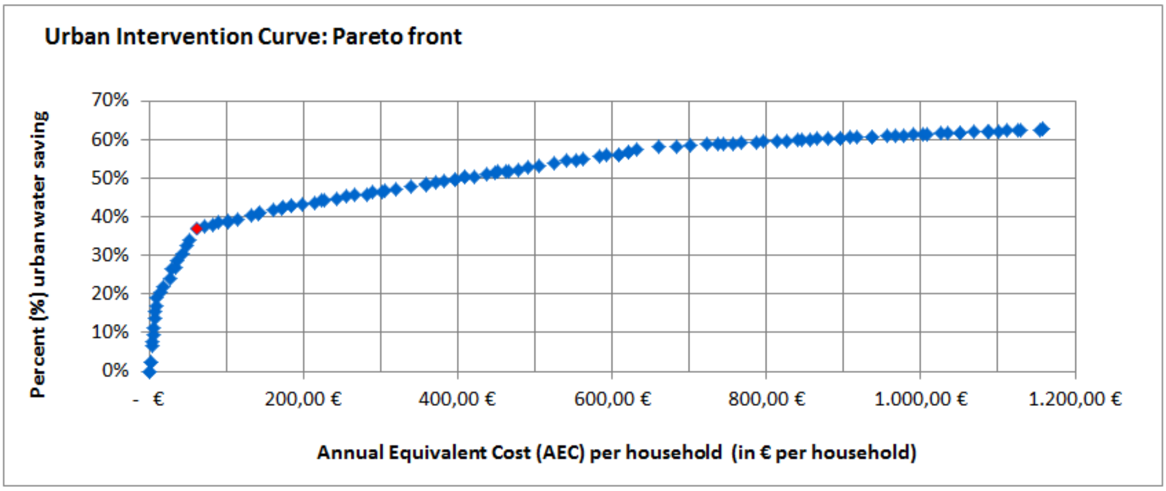

Figure 3.8: Cost-effective curve for the simulated urban demand management measures: percent water saving vs. AEC per household.

As shown in Figure 3.8 above it is relatively easy and entails relatively low cost to achieve conservation up to 34% with a cost of approximately 53 €/household AEC. Above that level of saving, and until the maximum level (62.7%) of water saving, the cost is increasing rapidly (as clearly depicted by the change of slope in the graph) until the maximum cost of about 1,158 €/household AEC. This is due to the algorithm selecting the relatively expensive measures of tier 2, such as rainwater harvesting and greywater reuse, as well as efficient washing machines of tier 1 to further decrease demand.

On the basis of the urban intervention curve, a user can select an option (point of the Pareto front) according to a target saving or a desired budget. This option translates into a mix of measures. For example, the red dot on Figure 3.8 represents an option with a

62€ AEC (per household) which renders a 37% water saving (as % of the total household consumption). To achieve this solution, the mix of measures to be implemented includes the installation of a dual flush toilet, the replacement of 1 showerhead and 2 low flow taps. When running the optimization for the total number of the households in the area of interest, divided under clusters, the optimum degrees of penetration for each solution are also depicted, i.e. the optimization will result in the optimal mix of measures and the number of households which should apply each measure within each cluster. It is sensible at this point to compare the equivalent unit cost in €/m^3 of water saved when applying a solution, with the existing total cost of water and the domestic water tariffs in the area. It is obvious that if this cost exceed the latter two it is unlikely that the community or individuals will be keen to implement them voluntarily since their implementation becomes too expensive, more than the actual cost of water. Upon selection of one or more pareto-suggested solutions, the measures should be simulated/ tested within a physical based model in order to assess their collective and disaggregated impact against the physical based reality of the area of interest. In the current research this has been implemented within the WEAP21 environment by scripting and tuning specific components of the developed water management model and running the necessary routines. This application also demonstrates the ability of the WEAP21 environment to support the modelling/simulation of demand management measures through its scripting options. Inter alia, suggestions on how to implement/embed the investigated demand management measures in WEAP21 by tuning specific model components and inserting new key variables are provided.

- **The agriculture intervention curves**

For the design of the agricultural intervention curves, the selected measures fovusing on increasing water efficiency by reducing conveyance losses, improving irrigation methods and investigating potential changes in the cultivated crops. More specifically, the following measures have been examined: replacement of open canals with closed pipes, switching to drip irrigation and/or sprinklers from furrow irrigation systems, apply deficit irrigation, implementing precision agriculture. Change of crops (% of the existing ones to new crops) has been proposed as an alternative solution, to be investigated individually, outside these demand management measures. In the case that multiple agricultural areas/clusters are present in the region under investigation, it is suggested to develop and apply agricultural intervention curves for each area separately. This is due to the fact that each agricultural area may have a completely different setting of collective and individual networks, open channels and closed pipes, irrigation methods, etc., thus different conveyance and irrigation efficiencies, and different potential combination in increasing this efficiency.

Similarly to the urban intervention curve design, in order to design the optimum agricultural cost-effective curves, the current methdodology proposes to run an optimisation process for each agricultural area/cluster.. The objective function of the optimization is to maximize the combined conveyance and irrigation efficiency while minimizing the AEC. The Matlab Global Optimization toolbox was used here, which incorporates NSGA-II, and a script has been developed for that purpose. The percentages that represent collective and individual networks remained constant (i.e. transactions for switching from individual to collective networks have not been implemented). The decision variables used are the conveyance methods (open channels or closed pipes) and the irrigation methods (furrow, sprinklers, drip irrigation). Every transaction from one method (conveyance or irrigation) to another has different effectiveness and different cost. The transactions to be examined are only those which could improve the efficiency, i.e. the case of moving from closed pipes to open channels was not taken in to account. Figure 3.9 presents a schematic representation of the optimization. The transactions from one method to one other are subject to constraints and cannot exceed their initial value. The variables named "Z_n" represent the area which will be irrigated with the specific method. Also variables Z1 and Z7 have an extra variable Z9 and Z10 respectevily which represent an area which applied precision irrigation[2] (advanced-with minimum monitoring). The colored lines (orange, red, green, brown, purple, and blue) represent the transactions. Note that each of them has different costs and benefits. The total decision variables are 15, one for each transaction (i.e. 13 arrows) and two for precision irrigation. An illustration of the results of the optimization for the two main

[2] Precision irrigation involves the accurate and precise application of water to meet the specific requirements of individual plants or management units and minimize adverse environmental impact. It involves application of water to the crop at the right time, right amount, right place and right manner thereby helping to manage the field variability of water in turn increasing the crop productivity and water use efficiency along with reduction in energy cost on irrigation (Shah and Das, 2012). Precision Irrigation is supported by technologies capable to measure soil moisture deficiency (many in real-time) so as to provide precise and/or real-time control of irrigation applications (Shah and Das, 2012).

agricultural areas of the Ali-Efenti case study (Karditsa and Trikala) is presented below (Figure 3.10). The resulting intervention curves demonstrate the initial efficiencies for the two areas and respective increases as a function of the AEC. Each point on the pareto front translates into a specific mix of measures and number of hectares to apply them.

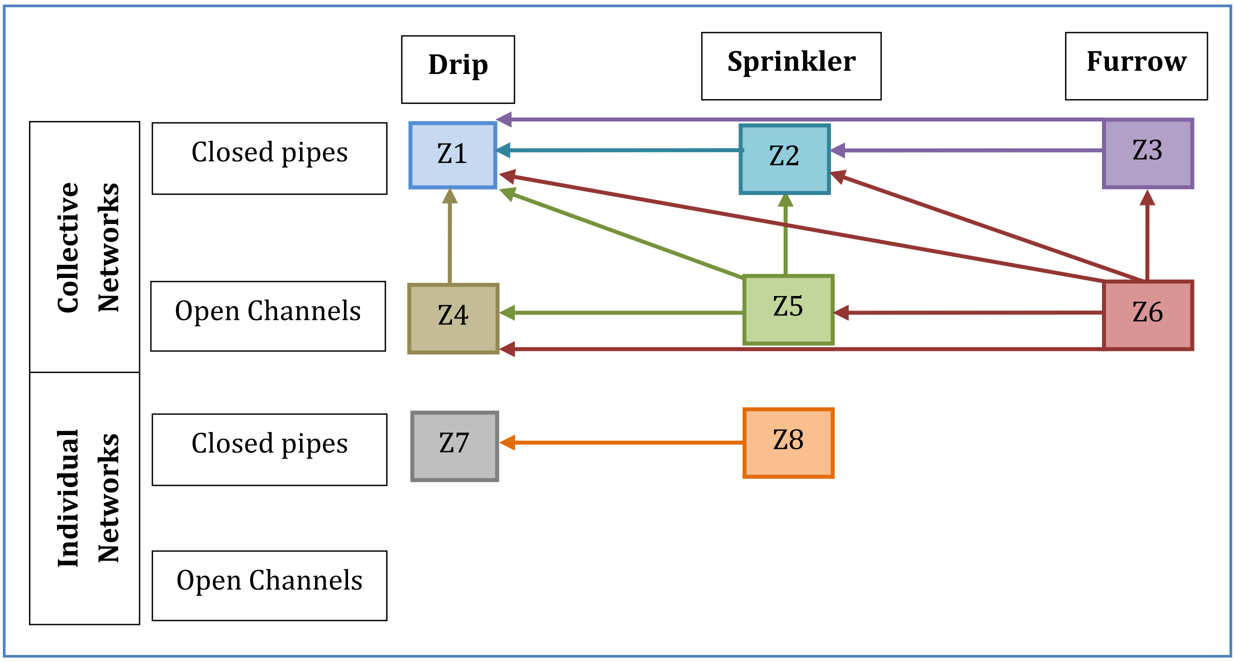

Figure 3.9: Schematic representation of the optimization process for developing agricultural intervention curves.

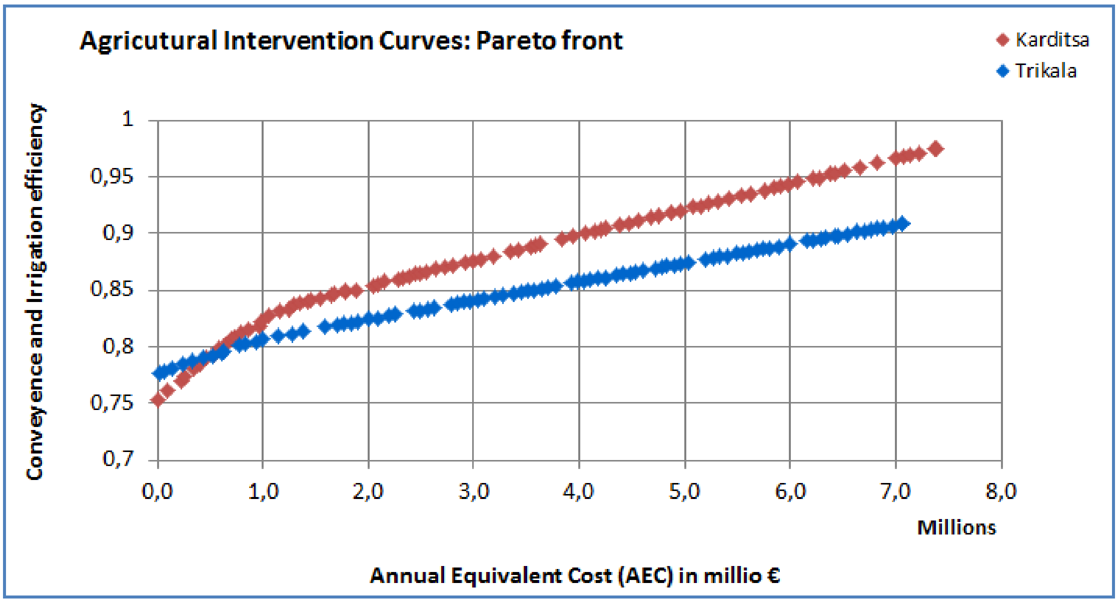

Figure 3.10: Karditsa and Trikala cost-effective agricultural curves.

Step 3: Prioritize DRM options: Optimization and Decision-making

The prioritization of the measures that can support drought management and risk reduction is often a key policy question which requires a decision-making process. In this step a methodology is proposed (and associated tools) to support this decision-making process. A Decision Support Platform is developed, linking the WEAP21 Water Resources Management Model (WRMM) with the Matlab optimization toolbox, with the purpose of identifying the optimum combination of demand management measures (on the basis of the intervention curves developed in the previous step 2), across two main sectors (urban and agriculture). The details of the methodology are presented in Chapter 6. The following components have been integrated into the Decision Support Platform (Figure 3.11):

1. The demand management measures and the associated intervention curves developed in the previous step 2.
2. An economic function that can adequately represent the cost of implementing the different measures, also detailed in the previous step 2.
3. An additional economic function which represents “deficit irrigation”, suggested as an additional measure on top of the ones simulated with the intervention curves.
4. A physical process-based model (WEAP21), which be used to adequately represent the impact of the applied measures on all demand and supply nodes within the area of interest, and subsequently calculate the resulting unmet demand and water supply reliability per node.
5. An evolutionary optimization algorithm that can provide an efficient method of searching through an extensive, non-linear and non-continuous solution space.
6. A programming environment (Matlab) to be used as the optimization engine for the selection of the optimum mix of measures against the specified objective function(s) and constraints, and to handle interaction with the WEAP21.

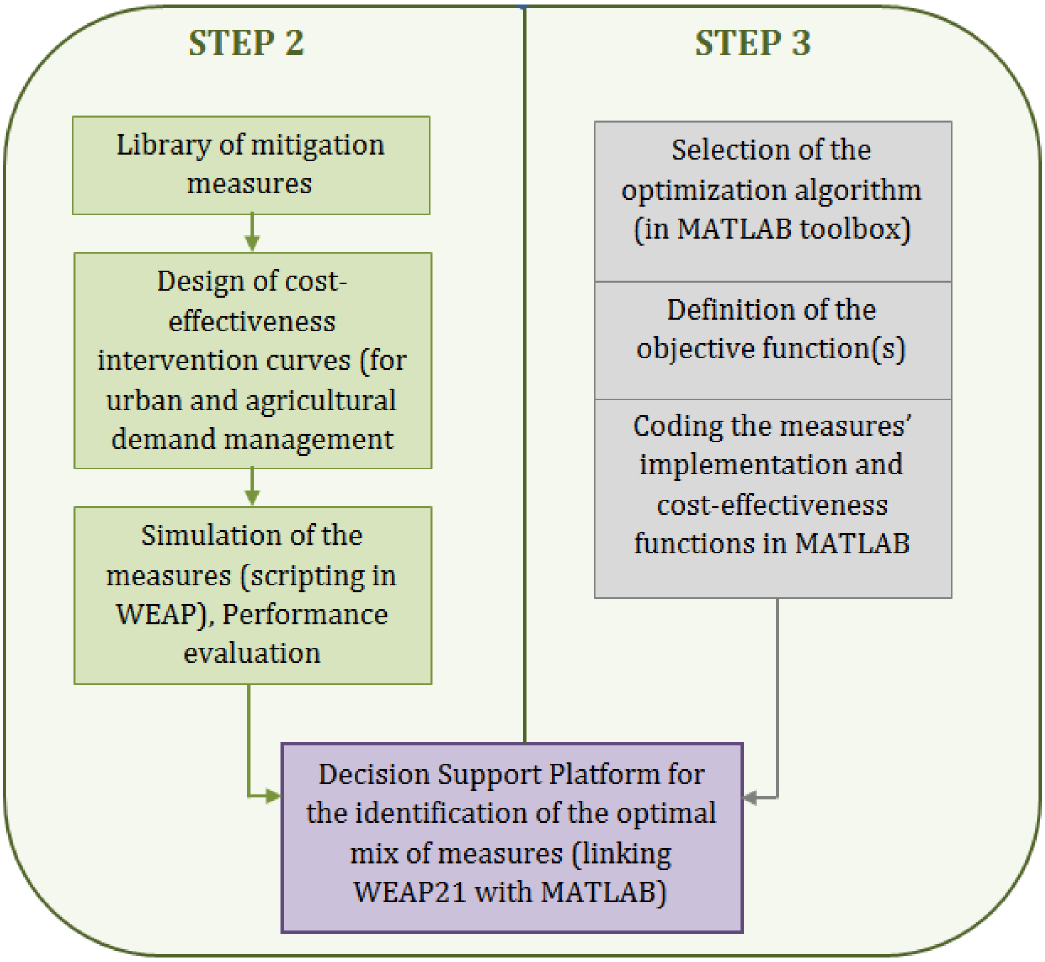

Figure 3.11: Overview Step 3 methodology and its links to Step 2.

The objective of the optimization is to select the optimum mix of measures, across the urban and agricultural sectors, which maximize water saving, thus minimizes the unmet demand, while minimizing the associated cost, either in terms of cost of implementation of the measures or farmers; income loss. The target unmet demand to be reduced can represent average conditions or a more conservative case (e.g. maximum observed unmet demand), and is up to the user to decide. The main tools used in the optimization are the WEAP21 and Matlab. The former has been used to evaluate the performance of the measures against the physical reality of the hydrosystem, while the later has been used to drive the optimization process.

In order to simulate the urban measures and implement the urban cost-effective curve (created in the previous step 2) into WEAP21 (i.e. the physical environment), a user-defined variable has been introduced, representing the percentage of water saved by applying urban water saving measures, which in turn affected the final water demand.

To implement the agriculture curves default WEAP21 variables were used. To implement the additional measure "deficit irrigation" in the WEAP21 model, specific subroutines and scripting have been developed. A user-defined variable has been introduced limiting the capacity of transmission links from 0-30% and thus, implicitly, applying less water for irrigation. Deficit irrigation implies a decrease on the crop evapotranspiration and crop yield, which in turn implies a decrease in farmer's income. That decrease was taken into account by introducing into WEAP21 data on crop yields and market values. Crop yields have been calculated as a function of the evapotranspiration and the yield response factor to water stress, while market values of crops have been calculated as a function of the cultivated area and the unit market price of each crop.

In order to run the optimization the Matlab Global optimization is used which incorporates the NSGA-II multi-objective algorithm. NSGA-II (proposed by Deb et al., 2000) is a fast and elitist multi-objective algorithm specifically designed to reduce computational complexity. NSGA-II is an improved version of the NSGA algorithm, using a more efficient non-domination sorting algorithm, selecting an automatically sharing parameter, and making the Pareto-front by an implicitly elitist selection method. As the algorithm progresses, it maintains population diversity for convergence to an optimal Pareto front by using the options 'ParetoFraction' and 'DistanceFunction'. The first limits the number of individuals on the Pareto front (elite members) and the second is an embedded crowding distance function that helps to maintain their diversity by favoring individuals that are relatively far from each other, while this diversity is either calculated in function (phenotype) or in the design space (genotype) (MATLAB, 2010). The decision variables for the optimization must equal the total number of the intervention curves, including an additional variable for deficit irrigation if the user wishes to run such a scenario. The lower and the upper limit of each variable are related to the corresponding cost-effective curve, while for deficit irrigation a range from 0-30% is suggested. A bespoke code developed in Matlab handles the interaction between the two programs (WEAP21 and Matlab) using the COM-API available in WEAP21. That interaction makes possible the bi-directional cooperation of both programs and the use of Matlab toolboxes. Figure 3.12 presents a flow chart of the simulation-optimization process. The main loop of the iterative process begins with the transformation of the decision variables into an appropriate format readable by WEAP21, then opening the connection to the WEAP21 through COM-API. The WEAP21 reads then the variables and calculates the results (unmet demand), which are exported to Matlab where the objective functions are calculated. The loop stops when the criteria are satisfied. The methodology has been tested in the Ali-Efenti basin in Greece.

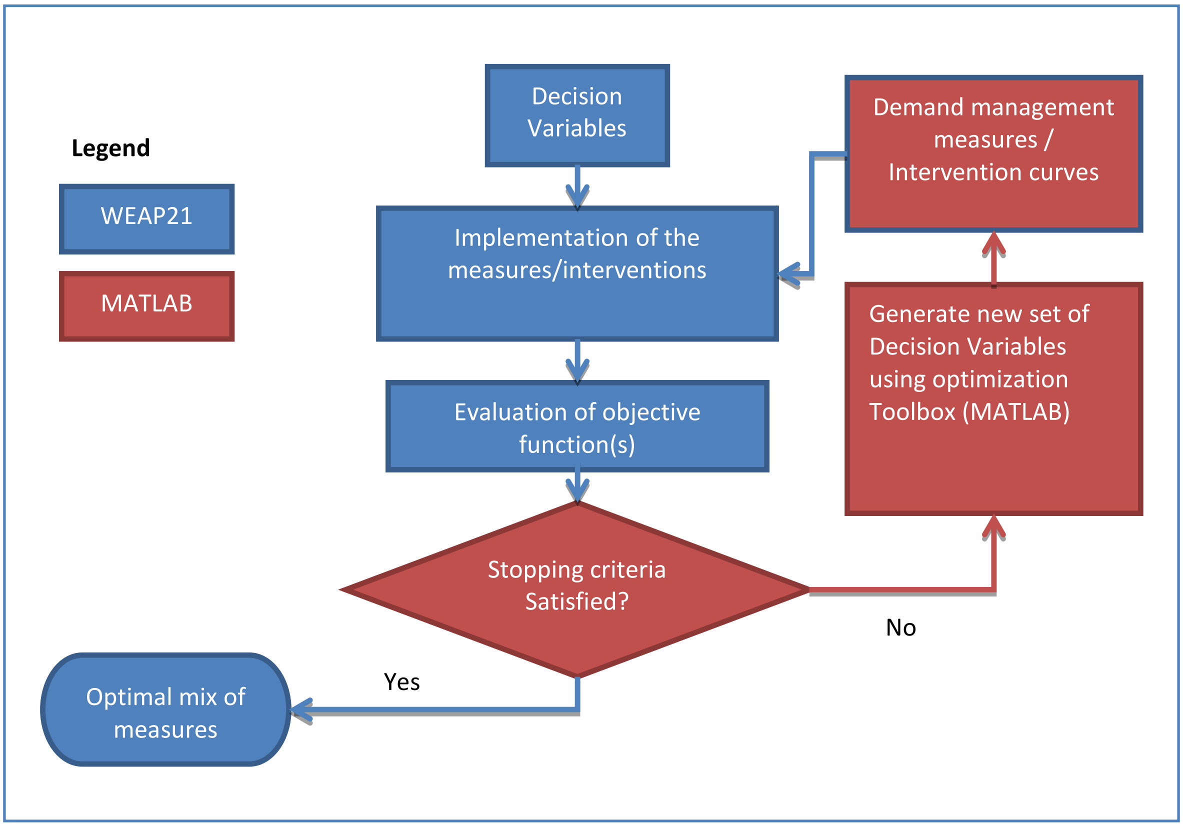

Figure 3.12: Flow Chart of the optimization process.

Step 4: Internalize DRM: Definition of policy targets and Implementation

The final step of the process aims at deriving indicative targets for reducing the vulnerability of the system under investigation, translating them into sectoral policy action, and internalizing them, along with the selected mix of measures, into local and national action plans and development frameworks. To achieve this goal the following methodological steps are proposed (Figure 3.13)

1. Develop future climate change and socio-economic scenarios (drawing on EU and/or regional accepted scenarios) with input from stakeholders.

2. Test the robustness of the optimization results under these future scenarios (against the baseline) and evaluate whether the proposed interventions can maintain their overall performance under future conditions.
3. Explore trade-offs between the optimal robustness-proof solutions in a transparent way, accounting for local specificities and priorities, and identify indicative Policy Targets per sector.
4. Assess the “reduced” drought risk as induced by the proposed adaptation measures/ policy targets.
5. Internalize Drought Risk Management (DRM) into development framework: draft suggestions how to implement DRM in action plans, development programmes, etc.
6. Disseminate, educate and raise awareness to the stakeholders and the general public.
7. Monitor the impacts of DRM mainstreaming once implemented.

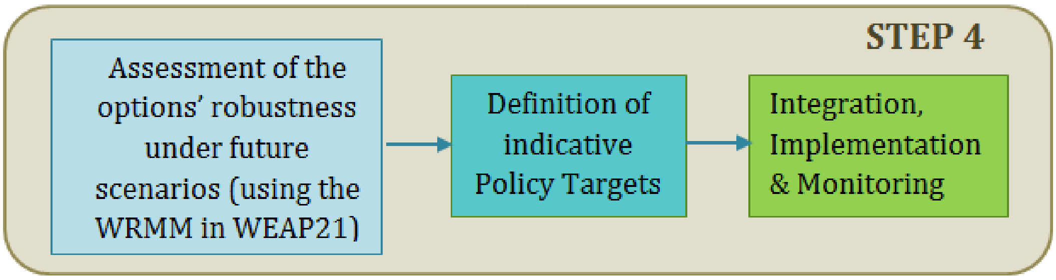

Figure 3.13: Overview of the Step 4 methodology.

3.4 Testing of the methodology

The above described methodology for supporting and mainstreaming drought risk management, with the subsequent methods and tools to implement each step, has been tested in the Ali-Efenti catchment of the Pinios River Basin in Greece. As described in Chapter 1 this pilot area has been selected as a case study due to its prevailing characteristics: frequent drought episode, extended irrigation areas with water demanding crops, imbalance between water availability and demand, structural unmet demand which peaks during the dry season, over-abstraction, degradation of water resources with associated environmental impacts, lack of robust institutions and policy instruments. A detailed description of the pilot test area, as well as the results and discussion on the methodology applied, are presented in Chapter 8.

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CHAPTER 4 - DEFINITION AND DEVELOPMENT OF A DROUGHT RISK PROFILE

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4 Definition and development of a Drought Risk Profile

4.1 Background

This chapter elaborates the development of an analytical framework for the characterization of water scarcity and drought (WS&D), and the development of Drought Risk Profiles (DRP). Disaster risk profiles in general, and thus DRPs in the case of drought, form the basis of implementation of the proactive risk reduction approach as recognized by different initiatives such as the of Hyogo Framework for Action (HFA) (UNISDR, 2012), the UN Advocacy Policy Framework (APF) on drought (UNCCD, 2013), etc. Risk profiling helps direct the policy and programmatic focus onto the underlying causes of droughts (risks) rather than their effects (impacts) (UNDP, 2011), since they show the combined physical and socio-economic pressure on a community at a specified scale (e.g. river basin, region, country, etc.) and help to determine who and what is at risk and why. Risks of drought disaster occurrence depend on the combination of exposure to natural hazard events and the social, economic and environmental vulnerability (or resilience) to these challenges in the affected communities (UNDP, 2011). Thus, the profiling of drought risk involves:

(a) the analysis of the climatic hazard,

(b) the subsequent analysis of vulnerability/resilience factors, using various indicators tailored to the context and specificities of the region under investigation,

(c) the combination/integration of the above two.

Although disaster risk profiles of different formats (matrix, curves, factsheets, maps, etc.) have been investigated for different disasters and hazards, and in some cases (such as floods) methodologies for developing them are well elaborated, in the case of drought risk profiles common and standard methodologies are lacking. In this chapter, a methodology for holistically mapping drought hazard and further assessing vulnerability to water scarcity and combining the two into a DRP has been developed. The proposed methodology is generic and can be extrapolated to drought prone areas. It is based on the use of operational and easy reproducible indicators, which detail the potential frequency and severity of the adverse effects of drought to which an entity is exposed. With regard to the identification, characterisation and mapping of the drought hazard, an indicator is developed and proposed, the so-called "Drought Hazard Index (DHI)", derived from monthly precipitation data, which captures all drought hazard components (recurrence, magnitude, severity, duration). The DHI is further integrated with socio-economic components to assess the associated vulnerability, which are blended into a Drought Vulnerability Index (DVI), and subsequently profile the resulting drought risk. The methodology and indicators are tested in the Ali-Efenti catchment in Greece.

Drought risk is a diverse concept, shaped predominantly by the underlying vulnerability. Vulnerability to drought cuts across different temporal and spatial scales, and different sectors: agriculture, livestock, domestic, tourism, etc. Hence, its definition requires detailed assessment of the prevailing socio-economic conditions, and at times it inevitably requires the prioritisation of the most important components and pressing factors which shape a region's potential risk. In the context of water stressed areas this pressing (or limiting) factor is usually the balance between water availability and demand, for the various economic sectors (including the environment) and at the relevant spatiotemporal resolution. Unmet demand, which is associated with different drivers (be it physical or anthropogenic), and water supply reliability, are commonly the limiting factors and main pressures leading to increased vulnerability conditions in periods of drought. In the current research a Drought Vulnerability Index (DVI) is developed on the basis of these parameters. It is nevertheless often that such data on unmet demand and water supply reliability are not available at an adequate disaggregation level (spatial, temporal, or sector-specific), and thus estimates and proxies must be used. In this context, the current research identifies that the development of adequate modelling frameworks which can capture and represent the salient features of the hydrological cycle on one side, and water users' needs on the other side (especially in data scarce cases) is a valuable tool in identifying and mapping these vulnerability components. The Water Evaluation and Planning System (WEAP21[1]) is investigated here for its capacity and flexibility as a modelling tool in delivering estimates of these components in cases of limited available primary data.

[1] http://www.weap21.org/

4.2 Review of common approaches used in assessing WS&D vulnerability and risk

4.2.1 Drought and Water Scarcity Indicators

Among the developed techniques for drought analysis and monitoring, unbiased indices should be widely used, but the subjectivity in the definition of drought and the complexity of drought phenomena have made it very difficult to establish a unique and universal drought index (Heim, 2002; Vincente-Serrano et al. 2010a; Hisdal and Tallaksen, 2000). Different indexes have been developed during the last decades for drought quantification, monitoring and analysis (Pisani et al., 1998; Heim 2002; Keyantash and Dracup, 2002). Their focus ranges from meteorological, to agricultural, to hydrological, while recent developments look into remote sensing-based indicators and more comprehensive aggregated indices (Niemeyer, 2008).

McKee et al. (1993) illustrated that the time scale over which water deficits accumulate is very important, and is the differentiating factor between hydrological, meteorological, agricultural, and other drought types. This explains the wide acceptance of the Standardized Precipitation Index (SPI, McKee et al., 1993), which can be calculated at different time scales to monitor droughts with respect to different exploitable water resources (Vincente-Serrano et al. 2010a). Bussay et al. (1998) and Szalai and Szinell (2000) assessed the utility of the SPI for describing drought in Hungary. They observed that agricultural drought (proxies of soil moisture content) was well replicated by the SPI on a scale of 2-3 months. Streamflow deficit was better captured by SPIs with time scales of 2-6 months, while strong relationships to groundwater level were found at time scales of 5-24 months. They concluded that the SPI was appropriate for quantifying most types of drought events. Guttman (1997) recommended using the SPI as the primary drought index for its simplicity, spatial invariance in the interpretation, and its probabilistic nature, features that make it ideally suited for use in risk and decision-making analysis. In this context, Hughes and Saunders (2002) presented a climatology for the incidence of 20th century European drought, based on monthly standardized precipitation indexes (SPIs) at time scales of 3, 6, 9, 12, 18 and 24 months for the period 1901-1999. However, SPI is limited because it does not account for the role and effect of evapotranspiration (ET). From a physical perspective, drought obviously depends a lot on precipitation, but it also depends on how much water infiltrates to deeper ground layers or runs off, and how much is evaporated or transpired by plants (Trenberth et al., 2013). Thus, to better capture the phenomenon, indexes based on precipitation and potential ET were developed. Tsakiris (2004) presented the Reconnaissance Drought Index (RDI). Recently, the Standardized Precipitation Evapotranspiration Index (SPEI), very similar to the RDI, was also proposed (Begueria et al., 2010; Vincente-Serrano et. al, 2010a, 2010b) as well as the Standardized effective Precipitation EvapoTranspiration Index (SP*ETI) incorporating, besides ET, the losses due to runoff (Maccioni et al., 2015). These last indexes combine the sensitivity of PDSI to changes in evaporation demand (caused by temperature fluctuations and trends) with the simplicity of calculation and multi-temporal nature of the SPI.

Palmer (1965) attempted to present a more comprehensive picture of the hydrological cycle, and proposed the Palmer drought severity index (PDSI) based on a soil water balance equation, which is one of the most widely used up-to-date. Nevertheless, the PDSI has several deficiencies (Vincente-Serrano et al. 2010a), mainly due to the parameters involved in the water balance equation that significantly depend on the calibration period. Thus, Wells et al. (2004) proposed the self-calibrated PDSI (sc-PDSI), which still presents some inability to adapt to the intrinsic multi-scalar nature of drought, while Burke et al. (2006) replaced the original Thornthwaite method used in the original PDSI PET calculation by a Penman-Monteith. The PDSI emphasis on soil moisture led to the development of explicit agricultural drought indices, such as the Crop Moisture Index (CMI) (Palmer, 1968), and most recently the Soil Moisture Drought Index (SMDI) (Hollinger et al., 1993), and most recently the Soil Moisture Deficit Index (SMDI) and the Evapotranspiration Deficit Index (ETDI) (Narasimhan and Srinivasan, 2005) calculated a high spatial and temporal resolution in order to capture short-term dry conditions.

An additional category of drought indices has been developed with a focus on hydrology, such as the Low Flow Q90, the Base Flow Index (Tallaksen and Van Lanen, 2004), and the Regional Streamflow Deficiency Index (RSDI) (Stahl, 2001)based on streamflow data. More comprehensive hydrological indicators include the well-known Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982) which incorporates snowpack, streamflow, precipitation, and reservoir storage, and the Aggregate Drought Index (ADI) (Keyantash and Dracup, 2004) which considers precipitation, streamflow, reservoir storage, ET soil moisture and snow water content.

The evolution of the Earth Observation and Global Monitoring for Environment and Security (GMES) systems with a focus on environmental monitored triggered the development of new drought indicators, based on earth observation data, mostly focused on vegetation and soil moisture parameters. As such, Tucker (1979) proposed the Normalized Difference Vegetation Index (NDVI), Peters et al. (2002) developed the

Standardized Vegetation Index (SVI), while more recent efforts focus on the use of information on land surface temperature (obtained from the optical domain and the thermal channels of the sensors) to derive drought indices (Kogan, 2000; Wan et al., 2004).

Concluding, a plethora of indexes of different complexity can be adopted for drought analysis. The last advances focus on combining and aggregating multiple indicators, into generating specialized drought indices, tailored to the context of the problem in-hand and making use of all available information (e.g. US Drought Monitoring, NDMC, 2008) The selection of an appropriate index which minimizes on one side the hydrological information required, while it is robust enough to accurately characterize the drought hazard is challenging. Based on that, among the objectives of the current research is to define a methodology for investigating the spatial and temporal variability of drought hazard based on a new index accounting for the intensity, magnitude, duration and frequency of drought events, which is based on easily obtained monthly precipitation data.

In the past 20 years many indices have also been developed to quantitatively evaluate water scarcity or water stress. The difficulty of characterizing water stress is that there are many equally important facets to water use, supply and scarcity. Selecting the relevant criteria to assess water scarcity can be as much a policy decision as a scientific decision (Brown and Matlock, 2011). Some simplistic approaches use indicators that express water scarcity in terms of the per capita water availability, based on the logic that having identified how much water is needed to meet human demands, the water that is available to each person can then serve as a measure of scarcity (Rijsberman 2006). An overview of the most commonly used water scarcity indices in decision making is presented below.

The **Falkenmark indicator** is perhaps the most widely used measure of water stress, defined as the fraction of the total annual runoff available for human use. Thus, based on the water use per capita an area can be categorized as: no stress (> 1,700 m^3/cap), stress (1000 - 1,700 m^3/cap), scarcity (500 - 1,000 m^3/cap), and absolute scarcity (< 500 m^3/cap) (Falkenmark 1989). The Falkenmark indicators is mostly used for highly aggregated country level assessments and at multi-annual scale, failing thus to reflect spatial and seasonal variability within a country and the particularities across regions. It is thus useful for high level awareness purposes.

The **Basic Human Water Requirements Index** was developed by Gleick (1996) to measure of the ability to meet all water requirements for basic human needs: drinking water, water for human hygiene, water for sanitation services, and modest household needs for preparing food. Minimum amounts of water have been allocated to each of these categories, namely: 5 liters per person per day for drinking requirements, 20 liters per person per day for basic sanitation, 15 liters per person per day for bathing, 10 liters per person per day for food preparation. These sums amount to a total water demand of 50 liters per person per day. This indicator is calculated on country-level so the identification of regional water scarcity is again hindered. Furthermore, country data about the domestic water use micro-components are hard to obtain and in many countries unreliable, while the water demand of other main users (e.g. irrigation, industry) are not considered.

Meigh et al. (1999) developed the **Water Availability Index** (WAI) that includes surface water and groundwater resources, and compares them with the total water demand of all sectors. WAI is expressed as the ratio of surface runoff plus groundwater resources minus water demand over the sum of these three parameters. The index is normalised to the range –1 to +1. When the index is zero, availability and demands are equal. The month with the maximum deficit or minimum surplus respectively is decisive.

The **Dry Season Flow by river basin** was developed by the World Resources Institute (WRI) (WRI, 2000)0 to describe the state of water resources at the river basin level. It considers the temporal variability of water availability as it accounts for the dry seasons. A dry season is defined when less than 2% of the surface runoff is available in a river basin in the 4 driest months of the year. The WAI is calculated by dividing the volume of runoff during the dry season (i.e. during the four consecutive months with the lowest cumulative runoff) by the population (data required are monthly time-series of surface runoff and population). This indicator may be relatively good for drought conditions, yet is doesn not consider the groundwater resources.

The **Water Resources Vulnerability Index** (Raskin, et al., 1997) was developed as the ratio of total annual withdrawals to available water resources. A country is considered water scarce if annual withdrawals are between 20 and 40% of the annual availability, and severely water scarce if withdrawals exceed 40%. This method and 40% threshold is commonly used in water resources analyses and has been termed the "criticality ratio"—the ratio of water withdrawals for human use to total renewable water resources (Alcamo, Henrichs and Rosch, 2000). The WAI fails to represent the spatial and temporal variability within a country.

Considering that the basin management is dynamic and holistic process, and assuming that the water sustainability of a watershed is a function of its hydrology (H), environment (E), life (L), and water resources policy (P), a dynamic, pressure-state-response model (OECD, 2003) was applied to those four indicators (H, E, L, P) in a matrix scheme. As a result, a **Watershed Sustainability Index** (WSI) was obtained:

WSI = (H + E + L +P)/4

Where, WSI (0–1) is the watershed sustainability index; H (0–1) is the hydrologic indicator; E (0–1) is the environment indicator; L (0–1) is the life (human) indicator; and P (0–1) is the policy indicator. In order to facilitate the estimation of the parameter levels by the users, both the quantitative and qualitative parameters were divided in five scale scores (0, 0.25, 0.50, 0.75, and 1.0). All the blended indicators have the same weight, since there is no evidence that it be otherwise (Harr, 1987). Although it is recognized that the indicator weights may vary from basin to basin, and should be chosen by consensus among stakeholders, using the same weight avoids skewing of the results (Heathcote, 1998), and allow for the equal representations among the different sectors. The parameters relative to each of the four indicators (H, E, L, P) are presented below. To each combination of indicators and parameters, a score between 0 and 1 is assigned. A value of 0 is assigned to the poorest level, and 1.0 to optimum conditions. Indicators and parameters of the Watershed Sustainability Index are presented below.

Table 4.1: Indicators and parameters of the Watershed Sustainability Index (WSI)

Indicators	Pressure	State	Response
Hydrology	Variation in the basin's per capita water availability in the period Variation in the basin BOD5 in the period analyzed	Basin per capita water availability (long term average) Basin BOD5 (long term average)	Improvement in water-use efficiency in the period analyzed Improvement in sewage treatment/disposal in the period analyzed
Environment	Basin's EPI (Rural and urban) in the period analyzed	Percent of basin area with natural vegetation	Evolution in basin conservation (percent of protected areas, BMPs) in the period analyzed
Life	Variation in the basin per capita income in the period analyzed	Basin HDI (weighed by county population)	Evolution in the basin HDI in the period analyzed
Policy	Variation in the basin HDI-Education in the period analyzed	Basin institutional capacity in IWRM	Evolution in the basin's IWRM expenditures in the period analyzed

Smakhtin, et al. (2005) developed the **Water Stress Indicator** (WSI) accounting for environmental water requirements as an important parameter of available freshwater. Mean annual runoff (MAR) is used as a proxy for total water availability, and estimated environmental water requirements (EWR) are expressed as a percentage of the long-term mean annual river runoff hat should be reserved for environmental purposes:

WSI = Withdrawals / (MAR – EWR)

Based on the WSI, a basin is classified as: over-exploited (current water use is tapping into EWR - environmentally water scarce basins) when WSI>1; heavily exploited (0 to 40% of the utilizable water is still available in a basin before EWR are in conflict with other uses - environmentally water stressed basins) when 0.6 ≤ WSI < 1; moderately exploited (40% to 70% of the utilizable water is still available in a basin before EWR are in conflict with other uses) when 0.3 ≤ WSI < 0.6; and slightly exploited () when WSI < 0.3. The authors applied this index in their global water resources assessment analysis using the WaterGAP 2 tool. The comparison of the maps illustrates that more basins show a higher magnitude of water stress when considering ecosystem water requirements, thus providing a more accurate assessment of regional water resource supplies.

McNulty et al., (2010) proposed the **Water Supply Stress Index** (WaSSI) to quantitatively assess the relative magnitude of water supply and demand at the 8-digit USGS Hydrologic Unit Code (HUC) level. This WaSSI is similar to the WAI, and has the following expression:

WaSSI = Water demand (WD) / Water Supply (WS), for either historic or future water supply and/or demand from environmental and anthropogenic sectors. Its calculation at the HUC watershed levels allows highlighting water stressed areas

that are typically overlooked in assessments of larger scales. WaSSI is unique from other water availability measurement tools in that it factors in anthropogenic water demand. Therefore, it is possible to have areas with high annual levels of precipitation which still a high WaSSI value.

Along the same lines, the **Water Exploitation Index** (WEI) (EEA, 2008) has been extensively used in Europe to demonstrate the level of exploitation of the renewable freshwater resources and thus provide metrics of water stress (Kossida et al., 2012).The WEI is defined as the ratio of annual water abstraction (from all sectors) over the total renewable freshwater availability (as a lumped sum of surface and groundwater resources). Traditionally the WEI has been applied at the annual resolution and country scale, but recognizing its limitations, work has been performed under the Water Framework Directive Common Implementation Strategy (WFD CIS) Expert Group on Water Scarcity and Drought (EG WSD) to improve its expression and scale of analysis. This effort resulted in the endorsement of the WEI+ by the Water Directors in Europe (in May 2012). The review and upgraded of the **Water Exploitation Index+** (WEI+) has been developed with the purpose of better capturing the balance between renewable water resources and water consumption, in order to assess the prevailing water stress conditions in a region. The WEI+ aims mainly at redefining the actual water exploitation, since it incorporates returns from water uses and effective management, tackling as well issues of temporal and spatial scaling. The EG WSD has agreed that the WEI+ would be formulated in these terms:

WEI+ = (Abstractions – Returns) / Renewable Water Resources

To correctly represent the problem of water scarcity and to meet awareness purposes, River Basin Districts or - following Art. 5(1) of the WFD - the portion of an international RBD falling within a Member States' territory have been defined as the spatial scale for the calculation of the WEI+. Other relevant scales may be the smaller River Basins that constitute RBDs, respectively their national parts or significant Sub-basins (and respectively their national parts) when relevant for water management. In some basins, water scarcity is reflected only when calculating the indicator at the monthly WEI+ but not necessarily captured by the annual WEI+. It is recognized that the monthly index level best represents seasonal shortages that may not be revealed in the annual scale, while the annual WEI+ may be enough where the absence of water scarcity problems is evident. Given that the application of the index on a monthly basis in some cases requires considerable effort in data acquisition, the EG WSD has recommended a two-step approach: In a first step the WEI+ at annual scale would be applied. Where appropriate and if data are available, WEI+ at monthly scale should be calculated either for every month or in the worst month where water scarcity situations could be expected. In any case, if the problem of data acquisition is adequately solved by the outputs of water balance models the monthly basis would be adopted as the general approach.

For the calculation of the denominator "Renewable Water Resources (RWR)" two alternative approaches have been proposed in order to suit more cases subject to different data availability. The hydrological balance equation, as applied in pristine basin unaffected by human interventions, has been used as a starting point. Thus:

$$ExIn + P - Eta - \Delta S = Qnat$$

Where: ExIn is the External Inflow

P is the Precipitation

ETa is the Actual Evapotransporation

ΔS is the Change in Storage

Qnat is the Natural Outflow

Both sides of the above equation may be identified with "Renewable Water Resources", and thus the 2 alternative approaches for calculating RWR are:

Option 1. RWR = ExIn + P – Eta – ΔS

Option 2. RWR = Qnat

Consequently, when applied in basins with human alterations, the observed outflow does not in fact equal RWR. For option 2, a flow re-naturalization is thus necessary. This correction can be made by restoring the consumption (abstractions – returns) and flow alteration linked with management, which may be approached by adding the variation in artificial storage:

Option 1. RWR = ExIn + P – Eta – ΔSnat

Option 2. RWR = Outflow + (Abstraction – Return) – ΔSart

It has been identified by the EG that both approaches present certain limitations. There are practical difficulties in incorporating the variation of natural storage (ΔSnat) in Option 1. In case this is neglected, the (P-ETa) at the monthly scale can render negative values. The calculation of the ΔSnat most often requires hydrological modeling and is not a parameter to be obtained for measurements as such. With regards to Option 2, the outflow should consider both surface and groundwater. In case of systems that are not groundwater dominated, one could assume that the surface outflow (i.e. streamflow at the outlet), which in fact includes baseflow, is representative enough. Yet, it is to be emphasized that in the case of non-pristine sites, where water abstraction is influencing the system, the observed streamflow does not represent the RWR. The necessary in these cases "naturalization" of the streamflow is a challenging process, especially in complex system of reservoirs and on the monthly basis. In case that a part of the water stored in the artificial reservoirs comes from a transfer (as opposed to generated within the territory of reference) or from a desalination plant, then the ΔSart needs to be carefully considered and corrected for the effect of these alternative water resources (i.e. water transfers, desalination). Both approaches present the limitation of not separating between surface water and groundwater resources, which is very relevant and should be explored at a later stage. Environmental Flows should be conceptually considered in the WEI+. At the moment, due to the absence of a harmonized and comparable method of calculation, Environmental flows are left out of the WEI+ formula itself, and should be considered instead in the definition of the relevant thresholds.

The elaboration of new thresholds for the WEI+ has not been finalized. Some methodological discussions were held within the EG WSD but the process has not been completed nor tested. It was commonly understood that thresholds should be defined on the basis of a relevant degree of vulnerability of the system. To this extend, it could make sense to have a common indicator, but define thresholds based on regional conditions (e.g. based on the storage level warrantee in countries were relevant as in Spain). Meeting environmental requirements (as expressed e.g. by the Eflow) is very relevant in this case, and stress thresholds could be associated to the degree that environmental water use is constrained (i.e. how much are we tapping into environmental needs). In this case the underlining methodology should be common and harmonized. The definition of thresholds has been identified as a very challenging issue. An intercalibration exercise may facilitate this process, but may be very complex.

Concluding, similar indicators providing some representation of water scarcity and stress, bearing different names and definitions are developed globally, as presented above and summarised in the following table. It is evident that no single common approach is adopted when it comes to characterising water stress conditions. Some of the indicators only provide some awareness-level relevant information since highly aggregated in terms of temporal and spatial resolution, while others attempt to identify hotspot areas adopting a smaller spatial scale of analysis. It is nevertheless apparent that no systematic assessment or framework is available.

Table 4.2: Overview of water scarcity and stress related indicators

Indicator / Index	Reference	Spatial Scale	Required Data
Water Exploitation Index (WEI)	EEA, 2010	Country, some RBs	annual freshwater abstractions long term annual availability (LTAA)
Water Exploitation Index= (WEI+)	WFD CIS EG WSD, in Faergemann, 2012	RBD, RB	annual (or monthly) freshwater abstraction and returns, annual (or monthly) renewable water resources (i.e. precipitation, external inflow, actual evapotranspiration, change in storage, natural outflow)
Intensity of use of water resources	OECD, 2001	country, region	annual freshwater abstractions total renewable water resources
Index of Watershed Indicators (IWI)	EPA, 2002	watershed	15 condition and vulnerability indicators
Exploitation index of renewable resources	Plan Bleu	country	
Water Stress Index (WSI) per source	EWP Water Stewardship Programme	Site specific	water abstraction/ consumption as percentage of available water per source (%) with the water abstraction volume per source in [m3/month or season] and average [m3/year]
Water discharge index (WDI)	EWP Water Stewardship Programme	Site specific	total amount of water discharge [m3/time period] in relation to total amount of available water body [m^3/time period

Indicator of water scarcity	Heap et al., 1998	country, region	annual freshwater abstractions desalinated water resources internal renewable water resources external renewable water resources ratio of the ERWR that can be used
Water availability index WAI	Meigh et al., 1999	region	time-series of surface runoff (monthly) time-series of groundwater resources (monthly) water demands of domestic, agricultural and industrial sector
Vulnerability of Water Systems	Gleick, 1990	watershed	storage volume (of dams) total renewable water resources consumptive use proportion of hydroelectricity to total electricity groundwater withdrawals groundwater resources time-series of surface runoff
Water Resources Vulnerability Index (WRVI)	Raskin, 1997	country	annual water withdrawals total renewable water resources GDP per capita national reservoir storage volume time-series of precipitation percentage of external water resources
Water Stress Indicator (WSI)	Smakhtin, et al., 2005	River basin	Annual water withdrawals environmental water requirements (as % of the long-term mean annual river runoff hat should be reserved for environmental purposes) mean annual runoff
Water Poverty Index (WPI)	Sullivan, 2002	country, region	internal renewable water resources external renewable water resources access to safe water, access to sanitation irrigated land, total arable land, total area GDP per capita under-5 mortality rate UNDP education index Gini coefficient domestic water use per capita GDP per sector Water quality variables, use of pesticides Environmental data (ESI)

4.2.2 Drought Vulnerability and Risk Frameworks

According to the UN International Strategy for Disaster Reduction Report (UNISDR, 2004) there are two essential elements in the formulation of risk: the potential event (hazard), and the degree of susceptibility of the elements exposed to that source (vulnerability). Their interaction can be described by the following mathematical formula: *Risk = Hazard x Vulnerability*. Therefore, a conceptual approach to drought risk assessment can be broken down into a combination of the hazard and vulnerability, i.e. the combination of the physical nature of drought (frequency, severity, extent) and the degree to which a system is vulnerable to the effects of drought. (Shahid and Behrawan, 2008).

Within the drought risk management framework, vulnerability pertains to consequence analysis. The concepts and definitions of vulnerability have been analyzed by many authors (Kates1985; Blaikie et al.1994; Downing and Bakker, 2000). The most common concept of vulnerability is that it describes the degree to which a socio-economic system or physical assets are either susceptible or resilient to the impact of natural hazards (Wilhelmi and Wilhite, 2002). It is determined by a combination of several factors (physical, social, economic, environmental) which are interacting in space and time. These include the conditions of human settlements, the infrastructure, the public policy and administration, the organizational abilities, the social inequalities, the economic patterns, etc. Vulnerability is thus inversely related to the capacity to cope and recover or adapt (Finan et al. 2002). Multiple methods have also been proposed to systematize vulnerability. They can be generally grouped under two perspectives, associated also with the evolution of the concept of vulnerability: (a) the technical or engineering sciences perspective, and (b) the social sciences perspective. The former focuses mostly on the physical aspects of the system and on the assessment of hazards and their impacts, while the role of human systems in mediating the impacts is downplayed (Blaikie et al., 1994; UNDRO, 2012). They thus explore the exposure to the hazard, the distribution of the hazardous conditions, their effects on people and structures, estimation of the potential damages (Burton et al. 1993; Cutter et al. 2000).

The social vulnerability perspective focuses on human system and on determining the capacity of the society to cope, respond and recover from the impact of a natural hazard (Blaikie et al., 1994), taking into account various factors that influence vulnerability (physical, economic, social, environmental, institutional) (UNISDR, 2004; Blaikie et al. 1994; Kelly and Adger 2000; Montz and Evans 2001). Relevant socio-demographic characteristics include age, socio-economic status, experiences, gender, race, and wealth. The latest approaches consider a “vulnerability of place” which integrates biophysical and social vulnerability within a particular geographic region; the approach not only considers the hazards themselves but the unique contexts within which they were imbedded (Cutter et al. 2000). They also emphasize on the need to account for external global factors, such as globalization and climate change. Thus, the broader the scope of the vulnerability assessment, the more interdisciplinary it becomes.

During the last decades, various conceptual models and frameworks have been proposed to quantify and measure vulnerability, with their own advantages and drawbacks, such as the "double structure of vulnerability", the "vulnerability within the context of hazard and risk", the "vulnerability in the context of global environmental change community", the "Pressure and Release Model" and the "holistic approach to risk and vulnerability assessment". Additional models include the "Sustainable Livelihood Framework" (Chambers and Conway, 1992), the "UNISDR framework for disaster risk reduction" (UNISDR 2004), the "onion framework" and the "BBC conceptual framework" developed by UNU-EHS (UN University, Institute for Environment and Human Security), the "DROP model (Cutter et al., 2008), and the most recent "MOVE model" (Birkmann et al. 2013). These conceptual models and frameworks incorporate, in general, parameters with reflect the physical, economic, social, environmental, political and institutional dimensions. The "double structure vulnerability" framework (Bohle, 2001) proposes an external and internal side, the former related to exposure to risks and shocks and the later related to the capacity to anticipate, cope with, resist and recover from the hazard impacts. This conceptual framework indicates that vulnerability cannot adequately be considered without taking into account coping and response capacity. The "vulnerability framework within the context of hazard and risk" considers hazard, exposure, vulnerability, and coping capacity as separate features (Davidson, 1997) which all together constitute the risk. On the contrary, the "vulnerability in the context of global environmental change community" conceptual framework couples the human-environment systems, and includes exposure, sensitivity and resilience (i.e. coping and adaptation) in the definition of vulnerability (Turner et al., 2003). The "Pressure and Release model (PAR model)" focuses in the drivers of vulnerability and their interaction (Wisner et al., 2004) and categorizes them as: (a) "root causes" (e.g. limited access to structures or resources, political and economic settings), (b) "dynamic pressures" (e.g. demographic and social changes, urbanization), and (c) "unsafe conditions" posed by the physical or socio-economic environment. This framework goes beyond the identification of vulnerability into the driving forces rooted in the human-environment system (Birkmann, 2006). The "holistic approach to risk and vulnerability assessment" incorporates three main factors which compose the vulnerability of a system: the physical exposure and susceptibility (which is hazard dependent), the socio-economic fragility, and the lack of resilience or ability to cope and recover (Kappes et al., 2012).

With regard to the diversity and lack of convergence among all the frameworks and models, Adger (2006) argues that is a strength and sign of vitality, not a weakness, of vulnerability research, while Eakin and Luers (2006) consider hybridization both a source of confusion, but also a trigger for new productive and creative debate.

While our ability to understand vulnerability is enhanced by these conceptual models, only some of them result in paradigms of quantitative or qualitative drought vulnerability assessments. A vulnerability assessment is the process of identifying, quantifying, and scoring the vulnerabilities in a system (CWCB, 2010), with an ultimate target to identify risk and define priorities, select alternative strategies or formulate new response strategies. Defining quantification criteria and methods is still a challenge (Babel et al., 2011; Downing et al., 2001). The most common assessment methods of vulnerability are vulnerability curves (intensity-damage functions), fragility curves, damage matrices, vulnerability profiles and vulnerability indicators or indices (Kappes et al., 2012). Indicator-based assessments are the most common and widely used, expressing drought vulnerability through a number of proxy indicators or through composite indices (Stathatou et al., 2014). The use of a composite index to assess the vulnerability could result into loss of information or over-simplification, as compared to the use of numerous indicators which allow for a more comprehensive analysis (Hamouda et al., 2009; Komnenic et al., 2009]. On the other hand, the condensed information provided by composite indices allows for a broad variety of issues to be addressed through a single value, and an easy communication to stakeholders and to decision makers, and they have thus been adopted in a number of water-related studies (Raskin, et al., 1997; Huang and Cai, 2009; Alessa et al., 2008).

In Table 4.3 below a review of different drought vulnerability assessments applied in various case studies is presented. A full list of identified studies that have performed drought vulnerability assessments in different areas in provided in Annex 2 of the dissertation. It is demonstrated that these assessments have several common aspects, regardless of the framework or school they are based on, as well as limitations which impede their comparability and reproducibility under different areas since they tend to be specific or context-dependent.

Table 4.3: Indicators and parameters used in different drought vulnerability assessments

Authors	Study scale	Exposure	Sensitivity	Adaptive capacity
Antwi-Agyei et al. 2012	Ghana (national)	▪ Long term growing season rainfall / ▪ Yearly growing season rainfall	▪ Crop yield sensitivity index = expected yield/actual yield	▪ Literacy rate (%) ▪ Poverty rates(%)
Bhattacharya and Das, 2007	India (subnational)	▪ Probability of drought ▪ Labour in agriculture ▪ Rural population ▪ Share of irrigation/unirrigated	▪ Income per capita ▪ Gini coefficient ▪ Fertilizer per hectare ▪ Tractor per hectare ▪ Share of fruit/vegetable ▪ Share of oilseed	▪ Human capacity (literacy and education expenditure) ▪ Governance (Share of tax revenue) ▪ Coping options (labor in HH industries)
CWCB, 2010	Colorado (subnational)	Not explained	Not explained	Not explained
Deems, H.J., 2010	Cyprus (national)	▪ Precipitation ▪ Drought	▪ Groundwater (aquifer characteristics) ▪ Presence of government irrigation scheme ▪ % of Irrigated area over agricultural areas ▪ Average Slope (%) ▪ Soil characteristics	▪ Total population ▪ Education distribution ▪ Age distribution ▪ Number of service institutions/population of community ▪ Number of people involved in associations/population of community ▪ % of farm holders that farm full time ▪ % of workforce that works within community ▪ % of workforce unemployed ▪ Insurance (€/agricultural holdings) ▪ Subsidies (€/agricultural holdings) ▪ Total agricultural area ▪ Agricultural area/number of holdings ▪ Number of animal units/number of holdings ▪ Number of different crop categories ▪ Number of different livestock categories
Fontaine and Steinemann, 2009	Washington (subnational)	▪ Drought frequency ▪ Drought severity: magnitude, duration, spatial extent	▪ Susceptibility of a water user	▪ Ability of a water user to manage or reduce adverse effects of a drought, through actions taken before, during, or after the drought
Gbetibouo and Ringler, 2009	South Africa (subnational)	▪ Extreme climate events ▪ Change in climate	▪ Irrigated land ▪ Land degradation Index ▪ Small scale farming operations	▪ Farm organization ▪ Literacy rate ▪ HIV prevalence

			▪ Rural population density ▪ Crop diversification index	▪ Access to credit ▪ Farm income ▪ % people below poverty ▪ Farm holding size ▪ Share of agricultural GDP ▪ Farm assets ▪ Infrastructure index
Iglesias et al., 2007	Cyprus, Greece, Italy, Morocco, Spain, Tunisia (national)	▪ Average precipitation 1961-90 (mm/year)	▪ Agricultural water use (%) ▪ Total water use (% of renewable) ▪ Area salinised by irrigation (ha) ▪ Irrigated area (% of cropland)	▪ GDP millions (US$) ▪ GDP per capita (US$) ▪ Agricultural value added/GDP (%) ▪ Energy use (kg oil equivalent per capita) ▪ Population below poverty line (% population with less that 1 US$/day) ▪ Human and civic resources ▪ Population density ▪ Agricultural employment (% of total) ▪ Adult literacy rate (% of total) ▪ Life expectancy at birth (years) ▪ Population without access to improved water (% of total) ▪ Agricultural innovation ▪ Fertiliser consumption (100 kg/ha of arable land) ▪ Agricultural machinery (tractors per 100 km2 of arable land)
Liu et al. 2013	Middle Inner Mongolia of China (subnational)	▪ Standardized precipitation Index (SPI)	▪ Coefficient of variance of precipitation ▪ Coefficient of variance of temperature ▪ Average Elevation Coefficient of variance of NDVI	▪ Per capita cultivated land area ▪ Physicians per 1000 persons ▪ Ratio of agriculture and industry output ▪ Technologists per 1000 persons ▪ Per capita savings deposi ▪ Per capita business volume of post and telecom service ▪ Population density ▪ Per capita GDP
Murthy et al., 2014.	Andhra Pradesh state, India (subnational)	▪ Total season rainfall ▪ Sowing period rainfall ▪ Total season rainy days Sowing period rainy days	▪ Season's Integrated NDVI ▪ Season's Maximum NDVI ▪ August NDVI ▪ Cropping pattern	▪ Soil (available water content) ▪ Irrigation support (% crop area irrigated) ▪ Land holdings (% crop area with small and marginal farmers)
Pereira et al.,	Brasil	▪ Aridity index	▪ Agricultural employment (%),	▪ HHs legally owned by farmer (%)

2011	(subnational)		▪ Smallholder farm's prod. system (%) ▪ Level of smallholder farming's income ▪ Dependence on vegetal and livestock production (%) ▪ Rainfed smallholder farms (%) ▪ Households (HHs) with access to water supply (%)	▪ HHs receiving technical assistance (%) ▪ HHs whose heads can read and write (%) ▪ HHs whose heads are engaged in associations or unions (%) ▪ HHs with access to electric energy supply (%)
Shahid and Behrawan , 2008	Bangladesh (subnational)	▪ Percentage of irrigated land ▪ Soil moisture holding capacity ▪ Food production per unit area	▪ Population density ▪ Female to male ratio ▪ Percentage of people living below poverty level ▪ Percentage of people depending on agriculture	Not explained
Stathatou et al., 2014	Argentina, Brazil, Chile, and Mexico (subnational)	▪ Coefficient of variation of rainfall ▪ Per capita water availability ▪ Water Exploitation Index (WEI) ▪ Wastewater discharge as percentage (%) of available water resources (WRP)	▪ Population density ▪ Population growth ▪ Percentage (%) of the total cultivated area dependent on irrigation (ID)	▪ Vegetation cover of the area ▪ Losses in the water supply network ▪ Irrigation water use efficiency ▪ Domestic, agricultural & industrial supply with reclaimed water ▪ Economically active population ▪ GRPD per capita ▪ Population below poverty line ▪ Governance of water supply and wastewater treatment sectors ▪ Legal & institutional WR&R framework
Swain and Swain, 2011	Bolangir district in western Orissa (subnational)	▪ Probability of drought occurrence ▪ Percentage of population living in rural areas ▪ Population density	▪ Area without any irrigation potential (%) ▪ Unirrigated area to total cultivable area (%) ▪ Paddy area variability (CV %) ▪ Paddy yield variability ▪ Households below poverty line (%) ▪ Landless and marginal laborers to total main workers (%) ▪ People illiterate (%) ▪ Geographical area not covered under forest ▪ Barren uncultivable and other fallows (%) ▪ Farmers not covered under crop insurance (%) ▪ People not benefited by IRDP (%)	

Source: adopted from De Stafano et al., 2015

Concluding, it is identified that the various methods and approaches for assessing drought vulnerability (and the resulting risk) are exemplifying the complexity around the issue. This complexity is attributed to the fact that drought vulnerability is (Vogel and O'Brien):

(a) multi-dimensional and differential (it varies for different dimensions of a single element or group of elements and from a physical context to another, with a wide variety of impacts strongly correlated to regional characteristics),

(b) scale dependent (with regard to the unit of analysis e.g. individual, local, regional, national etc.)

(c) dynamic (the characteristics that influence vulnerability are continuously changing in time and space)

This complexity is also further exacerbated by the existing conflicting views on the concept of vulnerability and its constitutive elements and key drivers (Urquijo et al., 2014). Consequently, there are still no universal frameworks, while consensus around the criteria, parameters and thresholds used has not been reached. For example, in developing countries, drought vulnerability constitutes a threat to livelihoods, the ability to maintain productive systems, and economies. In developed economies, drought poses significant economic risks and costs for individuals, public enterprises, commercial organizations, and governments (Downing and Bakker, 2000). Therefore, selection of vulnerability components is linked to the local study context (UNDP, 2004). The most important goal when developing tools or methods for assessing and quantifying drought vulnerability is their use in supporting risk reduction strategies, and their operational application in the decision-making processes. In this context, it is necessary to know the main objectives of the assessment, the target groups, the end-users of the results and their interpretation of the later (Ciurean, R.L. et al.)

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4.3 Methodological approach for the development of Drought Risk Profiles (DRP)

4.3.1 Overview of the methodological approach

The fact that water scarcity and drought (a) operate on many scales (spatial and temporal) and levels (moderate to severe), (b) are a complex result of both natural and anthropogenic factors, (c) have a wide variety of impacts affecting many economic sectors, and (d) mitigation is highly dependent on the prevailing socio-economic conditions and adaptive capacity of a system, makes it inherently difficult to frame a single pathway into assessing the nature and degree of vulnerability and subsequent risk (Kossida et. al., 2012). Nevertheless, as in all risks associated with climate change, key parameters which hold a central role do exist, and they need to be coherently and scientifically integrated (i.e. exposure, sensitivity, impacts etc.) into a framework which can support accurate communication and consistent analysis, eliminating ambiguous interpretation. Figure 4.1 presents a schematic of the key parameters that influence vulnerability and risk to water scarcity and drought and their interplay (adopted from Wood, 2011; Kossida et al., 2012) linking them to the DPSIR (drivers-pressure-state-impact-response) framework which is commonly used to guide the development of environmental indicators (Smeets and Weterings, 1999; Niemeijer and De Groot, 2008).

On the basis of this concept the current study proposes a methodology for developing Drought Risk Profiles and mapping them. This methodology involves:

(a) the development of drought hazard maps, focusing on the natural hazard characteristics, namely recurrence, severity, magnitude and duration

(b) the development of drought vulnerability maps, focusing on the reliability, sensitivity and resilience

(c) the assessment of drought and water scarcity risk, as an interaction of hazard and vulnerability, and the subsequent development of Drought Risk Profile (DRP).

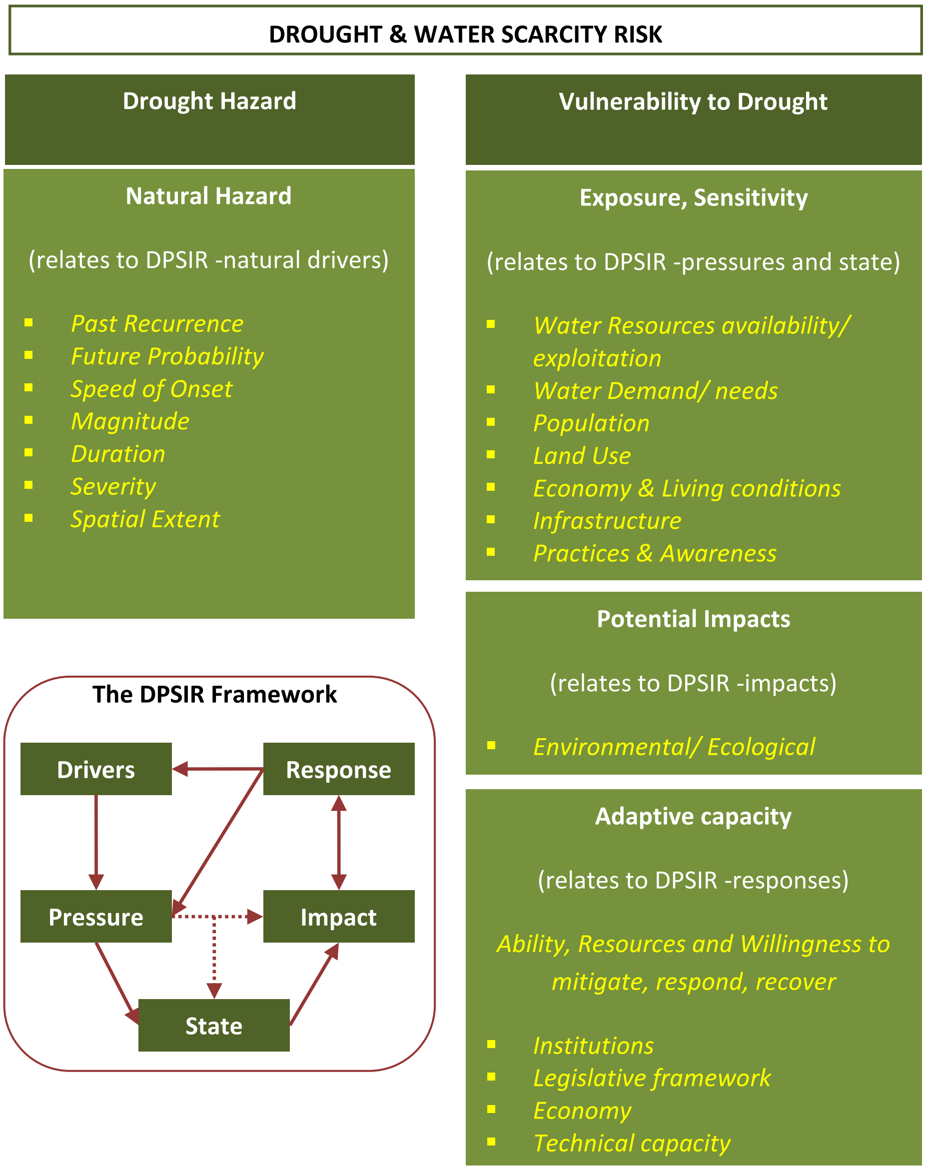

Figure 4.1: Conceptual schema of the components of drought and water scarcity risk, and their relation to the DPSIR

Source: Kossida and Mimikou, 2015, adopted from Wood, 2011.

The **drought hazard maps** reflect the spatial variability of the proposed Drought Hazard Index (DHI) and can been compiled following six methodological steps:

1. Analysis of the meteorological drought episodes in the catchment using the Standard Precipitation Index (SPI) (McKee et al., 1993) as a basis. Calculation of the 12-month SPI (SPI-12) from monthly precipitation data, for each rain gauge of the catchment and for a minimum 30-year period.
2. Post-processing of the SPI-12 results (meta-analysis) in each rain gauge in order to derive four new sub-indicators reflecting the frequency, intensity, magnitude and duration of the drought events.

3. Classification of the four sub-indicators and assignment of relevant scores for each rain gauge.
4. Blending of the four sub-indicators, using relevant weights, into a Drought Hazard Index (DHI) for each rain gauge.
5. Interpolation of the DHIs across the rain gauges to obtain coverage for the entire area and a corresponding drought hazard map.
6. Repetition of steps 2-5 for any desired sub-periods (e.g. 15-year periods) in order to assess the evolution and change of the DHI in time. Comparison of the corresponding drought hazard maps.

The **drought vulnerability maps** reflect the spatial variability of the proposed Drought Vulnerability Index (DVI) and can be compiled following four methodological steps:

1. Analysis of the components of physical and socio-economic vulnerability at a disaggregated spatial scale (the resolution depends on the area of interest). In the step, the development of a detailed water resources management/water balance model which can adequately represent the salient features of the hydrological cycle and the cause-effect relations between the physical (e.g. precipitation, inflows) and socio-economic parameters (e.g. water demand) is deemed necessary.
2. Selection of sub-indicators which can capture the reliability and sensitivity of the investigated system (within the constraints imposed by data availability). The suggested sub-indicators relate to the unmet demand and water supply reliability, and in can be derived as an output of a detailed water balance model.
3. Calculation and classification of the sub-indicators, and assignment of relevant scores for each calculation unit.
4. Blending of the sub-indicators in GIS, using relevant weights, into a Drought Vulnerability Index (DVI) for each assessment unit.

The **analysis of drought and water scarcity risk** is based on the interaction of drought hazard and vulnerability, and the associated maps can be compiled following two methodological steps:

1. Harmonization of the calculation units of the hazard and vulnerability maps
2. Overlaying in GIS to derive hazard maps following the basic relation Risk = Hazard x Vulnerability
3. Assignment of relevant classes to characterize drought risk

The above methodological framework for deriving Drought Risk Profiles is explained in further detail in the following sections. The methodology has been tested in the Ali-Efenti basin in Greece.

4.3.2 Assessment and mapping of the drought hazard

The Drought Hazard Index (DHI) is proposed as an indicator suitable to underpin the assessment and mapping of drought hazard. The DHI can be derived following the steps below:

- **Calculation and post-processing of the SPI-12**

The 12-month Standard Precipitation Index (SPI-12) is proposed as the basis for the analysis of the meteorological drought episodes since it can capture long-term precipitation patterns usually associated with streamflows, reservoir levels and in some cases groundwater levels. SPI is considered as a good and robust indicator to use as a basis for drought quantification as also demonstrated by Keyantash and Dracup (2002). In this report the authors performed an evaluation and comparative analysis cross commonly used drought indicators based on six criteria: Robustness, Tractability, Transparency, Sophistication, Extendibility and Dimensionality. Each investigated drought indictor received a 1-5 score for each criterion, finally blended into an overall grade using relevant weights for each criterion. The SPI was ranked second across the 18 indicators examined and with only 1 unit difference from the first one (SPI overall score 115; robustness: 5, tractability: 2, transparency: 3, sophistication: 5, extendibility: 5, dimensionality: 4).

The SPI was proposed by McKee et al. (1993) to provide a functional and quantitative definition of drought at different timescales (1, 3, 6, 12, … months) by quantifying the precipitation deficit. Computation of SPI involves fitting a probability density function (PDF) of cumulated precipitation (at different time scales of interest, i.e., 1,3,6,12,…months) for a station. For the SPI calculation the probability distribution of precipitation is of relevance (Sienz et al., 2012). In the original formulation of the SPI, the 2-parameters gamma distribution was proposed for its estimation (McKee et al., 1993). The gamma distribution is currently used to fit the frequency distribution of precipitation for the SPI calculation performed by the National Drought Mitigation Centre (NDMC, drought.unl.edu), Western Regional Climate Centre (WRCC, wrcc.dri.edu), and the National Agricultural Decision Support System (NADSS,

nadss.unl.edu), (Wu et al., 2007). The density probability function for the gamma distribution is defined as:

$$g(x) = \frac{1}{\Gamma(\alpha)\beta^{\alpha}} x^{\alpha-1} e^{-x/\beta} \qquad \text{for } x>0, \qquad (1)$$

where $\alpha>0$ and $\beta>0$ are the shape and scale parameters, respectively, computed through the Maximum Likelihood estimation, x is the amount of precipitation, and Γ is the gamma function. The α and β parameters are used to find the cumulative probability, denoted as $G(x)$, of an observed rainfall event for the given month and time scale referred to the precipitation and of a given station.

However, the precipitation distribution, especially for short time scales, may contain zero values, and, since the gamma distribution is undefined at x=0, the cumulative probability $H(x)$ is corrected as follows:

$$H(x) = q + (1 - q)G(x) \qquad (2)$$

where q is the probability of zero precipitation. Finally, $H(x)$ is transformed into the standardized variable, with a mean of zero and a variance of one, which is the value of the SPI. SPI values lower than -1 indicates dry conditions, while values greater than 1 indicate wet conditions. The drought intensity gradually increases from moderate (-1.49<SPI<-1.0) to severe and to extreme, when SPI values fall below -1.5 and -2.0 respectively (McKee et al., 1993).

It is worth noting, however, that several authors pointed out that the gamma distribution might lead to problems and does not fulfil goodness of fit criteria (Hughes and Saunders, 2002; Sienz et al., 2007). In this case, other distributions can be analysed, according to the recorded rainfall timeseries, in order to better estimate the SPI values.

The first step in developing the DHI is to calculate the SPI-12 (fitting a 2-parameter Gamma probability density function to the 12-month cumulative precipitation) for each rain gauge in the area of interest. The 12-month SPI allows for the comparison of the cumulative precipitation of 12 consecutive months every year within the selected study period. It presents the advantage of eliminating seasonality (applicable in smaller temporal scales) and capturing signals of distinctive wet or dry trends. Based on the values of the SPI-12 the drought episodes within the reference period can be been identified in each rain gauge. A drought episode is identified when the SPI-12 first falls below zero (onset of the episode) and continuous to increase reaching a value equal or less than -1. When SPI-12 reaches again its first positive value this event has ended. If an SPI-12 value equal or less than -1 has not been reached, then this event is not characterized as drought (i.e. it is just low precipitation event but cannot be characterized as a drought episode). Flowingly, the drought magnitude (DM) needs to be estimated for each drought episode at each station, applying the relation suggested by McKee (1993):

$$DM = -(\sum_{j=1}^{x} SPI_{12j}) \quad (3)$$

where *j* starts with the first month of a drought event and continues to increase until the end of the drought (x),

The second step involved the post-processing of the SPI-12 results to derive four new sub-indicators that can reflect the magnitude, severity, duration, and recurrence of the drought hazard in each rain gauge. The focus of this meta-analysis is to derive operational indicators each one reflecting common drought hazard characteristics, easy to reproduce, and blend into a Drought Hazard Index. The following sub-indicators have been defined, to be computed at each rain gauge:

FRQ: number of drought episodes (events) observed within the reference period (expressed as absolute number or as % over the total duration of the period of analysis). This sub-indicator is used as metrics of "recurrence".

FRQ24: number of drought episodes with duration greater than 24 months, within the reference period. This sub-indicator is used as a sensible descriptor of prolonged drought and thus metrics of "severity".

DMmax: maximum drought magnitude observed within the reference period. This sub-indicator is used as metrics of "magnitude".

dmax: maximum duration (in months) among the drought episodes observed within the reference period. This sub-indicator is used as metrics of "duration".

- **Classification and blending of the sub-indicators into the DHI**

Following the calculation of the four sub-indicators for each rain gauge, a classification must be elaborated, assigning four classes and relevant 1-4 scores (less to more significant) across all gauges. A classification has been performed in the current research when applying the methodology in the Ali Efenti catchments for a 30-year period (1981-2010), as well as for 15-year sub-periods. The thresholds for each sub-indicators' classes are elaborated in Table 4.4. In the case of the sub-indicators FRQ and FRQ24, the boundaries of the four classes defined for a 30-year period may slightly differ from the ones defined for 15-year sub-periods due to non-integral resulting numbers (i.e. 10% reflects 1.5 episodes in a 15-year period). Adjustments have thus been performed (Table 4.5). The suggested classification is presented below, yet it can be subject to adjustments when used in other areas based on the specificities of each case.

Table 4.4: Classification and scores of the drought hazard sub-indicators for a 30-year reference period

Classification thresholds for each sub-indicator				
FRQ *number of episodes (% over years of the period)*	**FRQ24** *number of episodes with d>24 months*	**DMmax** *maximum magnitude*	**dmax** *maximum duration*	**Assigned Score/ Class**
1 – 3 (≤10%)	1	≤ 35.0	24 – 36	1
4 – 6 (10.1% - 20%)	2	35.1 – 50.0	37 – 48	2
7 – 9 (20.1% -30%)	3	50.1 – 70.0	49 – 60	3
≥ 10 (> 30%)	4	≥ 70.1	≥ 61	4

Table 4.5: Classification and scores of the drought hazard sub-indicators for 15-year sub-periods

Classification thresholds for each sub-indicator				
FRQ *number of episodes (% over the years of the period)*	**FRQ24** *number of episodes with d>24 months*	**DMmax** *maximum magnitude*	**dmax** *maximum duration*	**Assigned Score / Class**
1 – 2 (≤13.3%)	1	≤ 35.0	24 – 36	1
3 (13.3% – 20%)	2	35.1 – 50.0	37 – 48	2
4 - 5 (20.1% - 33.3%)	3	50.1 – 70.0	49 – 60	3
≥ 6 (> 33.3%)	4	≥ 70.1	≥ 61	4

The final step of the calculation of the Drought Hazard Index (DHI) involves the blending of the sub-indicators. An Analytical Hierarchy Process (AHP) is suggested to assign relevant weights to each sub-indicator and blend them into the DHI. The AHP, developed by Saaty (1977), is a well-known weight evaluation method, widely used in a variety of decision making problems. For the estimation of criteria weights the AHP calculates the eigenvalues and the eigenvectors of a square preference matrix which contains the quantified preference information of all possible pairwise criteria constellations.

According to the AHP the four sub-indicators are set in a priority order and are compared to each other in a pairwise comparison matrix, in which their relative importance is expressed by numerical values. Saaty and Vargas (1991) suggested a scale for comparison ranking from 1, which expresses equal importance, to 9 which expresses "extreme importance" of one factor over another. Finally, a square preference matrix of fourth order is created, and the weights of the sub-indicators resulted from the eigenvectors of the matrix. The process resulted in equal weights for all four sub-indicators (i.e. they were all deemed of equal importance). As follows, the sub-indicators are blended to derive a DHI value for each rain gauge for the entire study period (as well as for sub-periods if desired) based on the following equation:

$$DHI = (\theta_1 \times score_{FRQ}) + (\theta_2 \times score_{FRQ24}) + (\theta_3 \times score_{DM\,\max}) + (\theta_4 \times score_{d\,\max}) \qquad (4)$$

where θ_i are the weights of the sub-indicators (all equal to 0.25 as resulted by the AHP).

The DHI values are expected to range from 1-4 (less to more prone to the drought hazard) since all the sub-indicators scores are 1-4 and their relevant weights are all equal to 0.25. The following classification is proposed for the DHI values (Table 4.6).

Table 4.6: Classification of the Drought Hazard Index (DHI)

DHI value	Score / Class
1.00 – 1.49	1 – low
1.50 – 1.99	2 – moderate
2.00 – 2.49	3 – severe
≥ 2.50	4 – extreme

- **Compilation of the Drought Hazard Maps**

The final step in the process is the compilation of the drought hazard map for the area of interest based on the derived DHI. The DHI values of each of the rain gauges used and for each of time period analysed are spatially interpolated using a two-dimensional minimum curvature tension spline technique, which is widely recognized among the standard approaches for surface interpolation based on scalar measurements at different points. Four neighboring points (rain gauges) are used for local approximation. The spline method estimates values using a mathematical function that minimizes the overall surface curvature. This results in a smooth surface that passes exactly through the input points. Conceptually, it is like bending a sheet of rubber so that it passes through the points while minimizing the total curvature of the surface (Childs, C.). It can predict ridges and valleys in the data and is the best method for representing the smoothly varying surfaces of phenomena such as temperature. There are two variations of spline: regularized and tension. The tension spline, proposed here, uses the first derivative (slope) and the second derivative (rate of change in slope), but includes more points in the spline calculations (as opposed to the regularized), so it usually creates smoother surfaces but increases computation time (Childs, C.).

The resulting maps present the spatial variability of the drought hazard in the catchment, as well as its evolution across the selected sub-periods (from the past to the most recent period allowing) for cross-comparison and policy relevant assessment.

The DHI has successfully been tested in the Pinios River Basin in Greece and the Tiber River Basin in Italy (Kossida and Mimikou, 2015; Maccioni et al., 2015).

4.3.3 Assessment of the water resources' availability and demand

The correct identification of the balance between water resources' availability and demand (either deficit of surplus) is considered an important socio-economic component in the assessment of vulnerability, as it lies at the heart on any drought risk assessment and drought management plan. Data scarcity per sector and user often prevents the accurate calculation of these components/indicators, and raises the need to develop suitable modeling environments, capable of assessing the availability of water resources across time and space. The accurate representation and simulation of all the necessary physical and anthropogenic characteristics is challenging and calls for flexibility and adaptability of the modeling tools. Furthermore, assessing the effect of different interventions aiming at reducing vulnerability to drought (e.g. application of demand management measures) requires testing against a modeled physical-based system which can simulate the causal relations under various scenarios. Thus, the necessity of developing water resources management models that can be used as central components of a wider Decision Support System becomes even more prominent.

In the current research the Water Evaluation and Planning System (WEAP21) has been tested and assessed as a modelling platform capable of supporting the estimation of the different components of the water balance even in cases of limited primary data. WEAP21 offers flexibility and allows building within the model necessary and customized cause-effect relations between drivers and pressures that allow the derivation of relevant estimates and proxies in case of missing data. For example, using key assumptions a user can estimate livestock water demand on the basis of number of animals and typical consumptions rates, irrigation needs on the basis of crops coefficients, PET and effective rainfall, etc. The model also offers flexibility in terms of spatial and temporal resolution. Water balance components can be estimated per node for each use category/sector, and be flowingly aggregated at different levels depending on the vulnerability analysis requirements. Similarly, results at the monthly scale are supported by WEAP, which can also be aggregated if desired at seasonal, annual or inter-annual scales. In the pilot application in the Ali-Efenti basin (Chapter 8), the WEAP software has been used to develop a distributed node-based Water Resource Management Model (WRMM) for the Ali-Efenti. Furthermore, its selection as a central component of a Decision Support System is justified by highlighting the capacities it offers in this context (e.g. scenario building function, possibilities to add user defined parameters, API, etc.).

4.3.4 Estimation of vulnerability to water scarcity and drought

Vulnerability to drought and water scarcity is a diverse concept. It cuts across sectoral spheres, e.g., agriculture, livestock and water, and is constantly evolving and changing over time and geographic areas. Hence, vulnerability assessment is a multidisciplinary task that requires inputs from various sectors. Defining drought vulnerability may at times inevitably entail various trade-offs. The complexity of its assessment requires a clear definition of the concept of vulnerability and associated terms, and thus, before undertaking any assessment, it is necessary to clearly define key questions of interest “whose vulnerability is being assessed?” and “vulnerability to what type of impact?” (Urquiji et al., 2014). In a context where drought vulnerability is attributed to numerous factors, the identification of the most pressing factors and the prioritization of corresponding risk management measures are necessary. In this context, total **unmet demand** is identified here as the main pressing factor and impact to mitigate. Total unmet demand is the part of the water users’ demand which was not covered by the available water supply, and represents the sum of the unmet demand from each economic sector, applicable in the regions of analysis (e.g. domestic, tourism, agriculture, livestock, industry). Unmet demand reflects thus the pressure caused on the society by the irregularity of the natural process, and incorporates different vulnerability components which are commonly discussed in literature, such as population, land use, irrigated areas, etc. since these are in fact the main drivers of the water demand (Table 4.7).It also incorporates, indirectly, the current practices in the area of analysis, since it is on the basis of these practices that unmet demand occurs. Should a change in practices (e.g. adoption of water saving measures) be implemented, this would normally be reflected as a decrease in unmet demand (rebound effects may of course be applicable here which can hinder the problem).

Table 4.7: Vulnerability components as captured by the "unmet demand"

Drivers	Pressure	State
▪ Population ▪ Daily water use per capita ▪ Rate of losses	▪ Domestic Water Demand ▪ Water supply delivered (as a function of availability and priority)	**Unmet demand in the Urban sector**
▪ Number of nights spent in touristic lodges (hotel, motel, etc.) ▪ Daily water use rate per lodge type (hotel, motel, etc.) ▪ Rate of losses	▪ Touristic Water Demand ▪ Water supply delivered (as a function of availability and priority)	
▪ Animals' population (per type) ▪ Typical daily water use rates (per animal type) ▪ Rate of losses	▪ Livestock Water Demand ▪ Water supply delivered (as a function of availability and priority)	**Unmet demand in the Agricultural sector**
▪ Crop types ▪ Irrigated area (per crop type) ▪ Irrigation needs (per crops type) ▪ Combined irrigation efficiency (conveyance, application)	▪ Irrigation Water Demand ▪ Water supply delivered (as a function of availability and priority)	
▪ Number of industrial units/facilities (per type) ▪ Daily water use rate per unit (per industry type) ▪ Return water from industry (inflow minus consumption)	▪ Industrial Water Demand ▪ Water supply delivered (as a function of availability and priority)	**Unmet demand in the Industrial sector**

On the basis of unmet demand, three sub-indicators are proposed to be blended into a vulnerability index, which reflect metrics of reliability, distance to target (to meet demand) and resilience to extreme conditions, as presented below:

REL: percent (%) of years with unmet demand within the period of analysis. This sub-indicator is used as metrics of "water supply reliability".

DIS: Average unmet demand within the period of analysis as percentage (%) of the respective total demand. This sub-indicator is used as metrics of "distance to target".

EXT: Maximum annual unmet demand within the period of analysis as percentage (%) of the respective total demand of that same year. This sub-indicator is used as metrics of "resilience to extreme conditions".

The above sub-indicators are to be applied across all sectors, but can also be applied per sector, if desired, flagging thus out the most vulnerable sectors. Table 4.8 to Table 4.9 present the suggested classification of the above indicators.

Table 4.8: Classification of the REL sub-indicator

% of years with unmet demand	Score / Class
0-9%	1 - low
10-19%	2 – moderate
20-29%	3 – high
>30%	4 – very high

Table 4.9: Classification of the DIS sub-indicator

Average Unmet demand as % of Total demand	Score / Class
0-9%	1 – low
10-19%	2 - moderate
20-29%	3 - high
>30%	4 - very high

Table 4.10: Classification of the EXT sub-indicator

Maximum annual unmet demand as % the total demand of that year	Score / Class
0-9%	1 – low
10-19%	2 – moderate
20-29%	3 – high
>30%	4 – very high

Upon calculation and classification of the above 3 sub-indicators, these are then blended into a Drought Vulnerability Index (DVI) using equal weights, using the following equation:

$$DVI = \frac{score_{REL} + score_{DIS} + score_{EXT}}{3} \quad (5)$$

In case different weights (i.e. not equal) need to be used, then the score of each sub-indicators should be multiplied by a relevant weight θ_i.

The DVI values are expected to range from 1-4 (less to more vulnerable to the drought hazard) since all the sub-indicators scores are 1-4 and their relevant weights are all equal. The following classification is proposed for the DVI values (Table 4.11).

Table 4.11: Classification of the Drought Vulnerability Index (DVI)

DVI value	Vulnerability class
1.00 – 1.49	1 – low
1.50 – 2.49	2 – moderate
2.50– 3.49	3 – high
3.49 – 4.00	4 – very high

The DVI can be obtained at different spatial and temporal scales depending on the level of the desired analysis. On the basis of the DVI vulnerability maps for the area of interest can be derived (River Basin District, River basin, sub-catchments) to allow for any easy visualization and comparisons. The DVI has successfully been tested in the Pinios River Basin in Greece (ref. to Chapter 8).

4.3.5 Development of drought risk profiles

As mentioned in the previous sections, risks of drought disaster occurrence depend on the combination of exposure to natural hazard events and the social, economic and environmental vulnerability (or resilience) to these challenges in the affected communities. Profiling of drought risk thus involves the characterization and analysis of climatic hazard and the subsequent analysis of vulnerability/resilience factors, using various tools and indicators.

The level of drought disaster risk is then measured by the combination of (a) the degree of exposure to a drought hazard, and (b) the level of vulnerability that a community (sector or system) faces (African Development Bank, et al., 2004). This concept is expressed in the following formula:

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \tag{6}$$

According to this principle, a large region subjected to exposure to a moderate drought hazard could be considered at the same risk level as a smaller region with a higher frequency and/or severity of drought hazards if the later more resilient. It is important to recognize, however, that this equation has no numerical value. There is no single real-valued measure that can quantify hazard and vulnerability (UNDP, 2011).

In the current research a composite index, the Drought Risk Index (DRI) is proposed as a tool to profile drought risk. The DRI is based on the combination of the Drought Hazard Index (DHI) and the Drought Vulnerability Index (DVI), presented in the previous sections, and can be calculated on the basis of the following equation. The suggested classification of the DRI is presented in Table 4.12 below.

$$\text{DRI} = \text{DHI} \times \text{DVI} \tag{7}$$

Table 4.12: Classification of the Drought Risk Index (DRI)

DRI value	Drought Risk class
1.00 – 2.00	1 – low
2.10 – 5.00	2 – moderate
5.10 – 8.00	3 – high
≥ 8.10	4 – very high

The DRI can be obtained at different spatial and temporal scales depending on the level of the desired analysis. On the basis of the DRI, the drought risk profiling can be easily visualized through maps derived for the area of interest (River Basin District, River basin, sub-catchments). Overlaying of the Hazard and Vulnerability maps in GIS may require some geoprocessing and spatial analysis techniques, depending on the scales used in the analysis and the map formats (e.g. reclassification, grouping, conversion of vector shapefiles to raster to allow calculations, etc.). The DRI has successfully been tested in the Pinios River Basin in Greece (ref. to Chapter 8).

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CHAPTER 5 – IDENTIFY OPTIONS: DESIGN AND SIMULATION OF ADAPTATION MEASURES

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5 IDENTIFY OPTIONS: DESIGN AND SIMULATION OF MITIGATION MEASURES

5.1 Background

This chapter elaborates the investigation of the effect of a "Demand Reduction Policy", based on a bundle of technological and management measures which promote water saving and efficiency gains in the urban and agricultural sectors. To simulate these measures generic "intervention curves" have been developed for each sector (i.e. urban and agricultural), which basically simulate response functions of water saved vs. investment cost for a mix of measures. To develop these curves an optimization process has been applied in Matalb. To further select the optimum combination of demand management measures, in terms of cost-benefit, across the two sectors, an optimization module has been developed in Matlab as discussed in the following Chapter 6.

The bundle of measures investigated could benchmark the effect of an "alternative policy" focused on demand reduction across the main economic sectors. The recent assessment of the Water Framework Directive River Basin Management Plans (WFD RBMPs) showed that water supply measures are significantly stronger reflected in the screened set of plans (about 30-40% of RBMPs) than restrictions of pressures (e.g. new water-demanding urban or agricultural developments) or measures to ensure the achievement of the environmental WFD objectives under water scarcity and drought conditions (EC, 2012). Furthermore, evidence on the impacts of the applied response measures is limited and no concrete conclusions can be drawn on their effectiveness (Schmidt and Benitez, 2012). It is thus important to simulate response measures (and a bundle of them) against the physical system, in order to test their application and assess their true potential under specific conditions and constraints. The process of testing response measures can be underpinned by their simulation in a physical-based distributed water resources management model (WRMM), which can capture all the salient features of water availability and demand per source and user. It is yet clear, that simulating each and every measure and technology is a time consuming process, while consensus on the optimal mix of measures requires the additional application of optimization algorithms, explicitly tuned for the specific WRMM, adding further complexity and processing time. To this extent, the current suggestion of developing generic "intervention curves" is of added-value, since it is:

(a) Parsimonious: the optimization process leading to the definition of the optimal mix of measures is carried outside the WRMM, and selected solutions of the pareto front can be then simulated in the WRMM at a second step. This saves important computational time.

(b) Adaptable: the intervention curves can be adapted and updated at any time, just by changing the primary input data (e.g. costs)

(c) Expandable and reproducible: adding or removing technologies to/from the intervention curves is easily handled, in order to tailor them to specific areas and contexts.

The following methodological steps must be implemented in order to build the intervention curves and simulate, as described in detail in the following sections of this Chapter:

- Definition of the economic sectors of interest, and selection relevant measures (per sector) in consultation with local stakeholders
- Adaption of clear definitions for all measures and interventions
- Collection of the input data needed for the curves (potential saving, costs)
- Development of the curve, implementing an optimization process and relevant scripting (Matlab was used in the current research)
- Investigation on how to simulate the curves (and/or selected pareto solutions) in a physical WRMM model (coding routines) (the WEAP21 model has been investigated in the current research)
- Simulation of the selected solutions against a baseline scenario, and assessment of their impact and cost-effectiveness on the physical system

5.2 Selection of demand management measures

The selected demand management measures focus on water saving in the urban sector, as well as on leakage reduction and improved irrigation practices in the agricultural sector, as presented in Table 5.1. These measures were selected in consultation with local stakeholders and based on the following criteria: technical feasibility, water saving potential, potential risks, costs (investment & maintenance), social acceptability, additional benefits (energy savings, water bill reduction, reduction of wastewater generation, increased yields, water supply security). These criteria enabled the initial screening and elimination of "less suitable" measures and shaped the options of the demand reduction policy.

Table 5.1: Selected measures used for simulating the proposed demand reduction policy

Sectors	Measures for water saving and/or improved irrigation efficiency
Urban	1. Low water using appliances (low flow taps and shower heads, dual toilet flushes, efficient washing machines, dishwashers, etc.) 2. Rainwater Harvesting (RWH) 3. Domestic Greywater Reuse (GWR)
Agriculture	1. Replacement of open canals with closed pipes 2. Change of irrigation methods ▪ Switch to drip irrigation and/or sprinklers from furrow irrigation systems ▪ Apply deficit irrigation ▪ Precision agriculture

5.2.1. Options for the urban sector

There is a variety of available technologies designed to deliver domestic water saving targeting the different household water uses. These include a range of low water using appliances and retrofitting, as analytically presented below.

Toilet flushes, usually accounting for one third of the domestic water use on average (Benito et al., 2009), can deliver reductions up to 50% of the water used. Common options include the replacement of older style single-flush models (14 lt/flush) with low-flush gravity toilets (6 lt/flush), dual-flush valve operated toilets (4 lt/flush), airassisted pressurised toilets (2 lt/flush). Evidence exists that flush volumes down to 4 lt do not cause any problems in the drains and sewers in terms of the waste disposal (Lillywhithe et al., 1987).

Taps and **Showerheads** can be adjusted and render saving by installing water saving devices and inexpensive retrofits. Various options are available for retrofitting kitchen and bathroom taps, which are estimated to account for more than 15% of domestic indoor use (MTP, 2008), with respective savings of 20-30% and less than 2 years paybacks: fitting of new water efficient tap-ware (spray taps, push taps, etc.), low-flow aerators, durable tap washers, flow restrictors and regulators, automatic shutoff (BIO and CU, 2009). Showerheads are usually gravity fed, electric or pumped (power showers). The average consumption of showers ranges across the households as it depends on many interrelated factors: frequency of use (from 0.75-2.5 showers/day) average shower time duration (2-5 minutes), type of shower, flow rate (6-16 lt/minute), etc. Yet, evidence exists that showers and baths account for 20-35% of the household water consumption (EA, 2007; Memon and Butler, 2006; Dworak et al., 2007) and installing water saving devices (flow restricting devices, low-flow showerheads - aerating or laminar-flow, cut-off valves, etc.) can secure around 30-40% water savings. It worth mentioning that the expected savings from the installation of smart water saving devices in taps and showerheads is also highly influenced by the use patterns and habits of the users, and the adoption from their side of an overall water saving culture which can influence their daily behaviour: turning-off the taps while brushing their teeth, shaving or shampooing, filling the sink vs. keeping the faucet running continuously when rinsing fruits and vegetables, reducing the shower duration and avoiding filling-up the bathtub, etc.

Washing Machines and **Dishwashers** can be replaced with more efficient ones delivering water and energy savings. Washing of clothes is probably the third largest consumer of domestic water, around 20%. Installing high-efficient washing machines can save up to 40% of the volume need per cycle. Modern washing machines use about 50 lt/cycle or 35 l/cycle for the most efficient ones, as opposed to 150 lt/cycle in the 1990's, due to technological advances (i.e. intelligent sensor systems, advanced and customised washing programmes, improved time functions, etc.) (BIO and CU, 2009). Dishwashers manufactured prior to the year 2000 typically consume 15-50 lt/load, while modern dishwashers consume 7-19 lt/load under normal setting and as low as 8-12 lt/load under the eco-setting (BIO and CU, 2009), which means average water savings at the range of 40-60% . The share of water use consumed by dishwashers varies from 6-14% (Benito et al., 2009) as it depends on the cycle time, the frequency of use and their degree of penetration in the households, the latter being influenced by e.g. lack of space, conception that this investment is not necessary due to small load of dishes feasible to be hand-washed, etc.

Traditionally, wastewater and rainwater were considered waste streams in the urban water cycle, which needed to be conveyed away from the urban environment and disposed. However, they are increasingly being considered as resources that need to be exploited, rather than unavoidable by-products of urbanization (Makropoulos et al., 2008).

Greywater is the dilute wastewater, originating from domestic activities such as showering, bathing, washing hands, tooth brushing, dishwashing, washing clothes, cleaning and food preparation, in brief it refers to all household wastewater other than wastewater from toilets (the so called blackwater). This water contains some organic material (Wheatly and Surendran, 2003), yet it can be reused for some uses within the households (e.g. toilet flushing) (Friedler, 2004). Greywater from baths, showers and washbasins is less contaminated than that from the kitchen (EA, 2011). According the Joint Ministerial Decision (JMD) 145116/2011 of March 2011 (JMD, 2011) on the definition of measures, conditions and processes for the reuse of treated wastewater, which complies with the Urban Wastewater Treatment (UWWT) Council Directive 91/271/EEC (EC, 1991), four options regarding the use of reclaimed wastewater have been introduced in Greece, each one with specific constraints: reuse for irrigation purposes, reuse for aquifer recharge, urban and suburban reuse, industrial reuse. Reuse in the urban and suburban environment primarily concerns irrigation of green areas, recreation and swimming activities, natural landscaping, fire-fighting, cleaning of streets, and domestic uses with the exception of drinking use. Typical domestic reuse systems collect and store greywater before reusing it to flush the toilet, while more advanced systems treat greywater to a standard that can be used in washing machines and garden irrigation. The most basic systems (i.e. direct reuse systems) simply divert untreated bath water, once cooled, to irrigate the garden (EA, 2011). More advanced systems include short retention systems (which apply the very basic treatment of debris skimming and particles settling), basic physical and chemical systems (which use a filter and chemical disinfectants to stop bacterial growth), biological systems (which use bacteria for organic matter removal), bio-mechanical systems (which combine biological and physical treatment) (EA, 2011). The advantage of onsite domestic reuse of greywater is that the supply is regular and independent of external conditions, such as rainfall. Different systems can be used based on the cross-section of different technologies as previously mentioned, such as filtration and chlorination, advanced oxidation (H_2O_2 + UV), membrane bio-reactor (MBR), biological with media filter, ranging thus in costs (from 1,900-6,500 € for the equipment purchase and installation, and 36-420 € for maintenance), and the effluent water quality (Kuru and Luettgen, 2012). Greywater used for flushing toilets can render savings around 20-30% of the average household water use depending on the toilet flash volume. In the UK studies showed water savings from about 5-36% introduced when using greywater reuse systems (NWDMC, 2000).

Rainwater Harvesting (RWH) is defined as “the capture, storage and management of water flowing on the roofs of buildings and river basins that exist on the ground with the purpose of growing crops, regeneration of pasture for animal feed production and farming in general, horticulture and domestic use” (Ngigi, 2006). Typical RWH systems consist of three basic elements: the collection system (area which produces runoff because the surface is impermeable or infiltration is low), the conveyance system (through which the runoff is directed, e.g. by bunds, ditches, channels, pipes) and the storage system (where water is accumulated or held for use). The storage system consists of tanks or impermeable soil and subsoil, as well as larger reservoirs. The collection of rainwater includes, according to FAO (Food and Agriculture Organization of the United Nations), techniques that engage the "ephemeral" runoff from roofs of buildings and land surfaces, for the productive use of water in the agricultural or domestic sectors (Critchley and Siegert, 1991). In the context of urban water cycle, RWH aims to minimize the effects of seasonal variations in water availability due to droughts and dry periods, and to enhance the reliability of domestic water supply and reduce the dependence on the mains water supply. Additional benefits include effective management of surface runoff, mitigation of flooding and soil erosion, increased productivity of domestic crops, reduction of water bills, etc. Nevertheless, there are limitations in implementing RWH techniques or relying on RWH as a source of supply, the main disadvantage being the unpredictable and often irregular supply which results in large storage space requirements (Dixon et al., 1999). Larger schemes and structures are difficult to implement as they need acceptance by people, political backing and financial support. Finally, as rainwater usually carries small pollutant loads (depended on the location, roof building materials and collection system construction), a main light treatment and disinfection is generally needed for rainwater treatment to non-potable standards. Numerous RWH systems are available with a range of features and varying costs. Usually they differ in the way water is delivered to the points of use, i.e. pumped directly to points of use from the storage tanks, fed by gravity to points of use, pumped to an elevated cistern and fed by gravity to the points of use (EA, 2010). Studies in France (Le Monde, 2007) demonstrate that the rainwater harvesting potential of a typical family house reaches 108,000 litres of rain covering thus about 80% of the household needs, while savings in the UK (EA, 2010) range between 30-50%. In any case, the amount of available rainfall, the collection area (roof area, etc.) and the installed storage capacity (i.e. size of the storage tank) influence the potential average saving from the water mains. A relevant study on the relation between rainwater tanks volume and water savings in Australian cities (Adelaide, Brisbane, Melbourne and Sydney) resulted in annual mains water savings ranging from 18-55 kL for 1 kL rainwater tanks, to 25-144 kL for 10 kL rainwaters tanks (Coombes and Kuczera, 2003). Costs vary from as low as 2,000 € to as high as 8,000 € depending on the size and type of the tank (e.g. 2,000-8,000 lt), the timing of installation (retrofitting vs. installation during construction), the pumping system, additional desired UV treatment, etc.

Information on the expected savings and costs of each of the above mentioned interventions has been collected from various literature sources as presented in Table 5.2 and Table 5.3below. On this basis, the % expected saving and costs have been identified, to be subsequently used in the development of the urban "intervention curve" in the next section.

Table 5.2: Potential water saving per household water using product (WuP).

HH Water Using Product (WuP)	Consumption of "traditional" WuPs			Consumption of "efficient" WuPs	Water Saving		
	lt/use	Frequency of use per day	Average consumption in lt/hh/day	lt/use	lt/hh	as % of WuP's consumption	As % of total HH consumption
Low flush WC	6-12 lt/flush	7-11.6	101.8	3-4.5 lt/flash	30-170 lt/day	30-50 %	26%
Showerhead	25 lt/min; 25.7-60 lt/shower	0.75-2.5	91.8	6-14 lt/min	25 lt/day	50-70 %	8 %
Faucet aerator	13.5 lt/min; 2.3-5.8 lt/use	10.6-37.9	74.6	2-5 lt/min	12-65 lt/day	40-65 %	7-11,6 %

Dishwasher, AAA class	21.3-47 lt/load	0.5-0.7	24.3	7-19 lt/load	5,000 lt/year	40-60	4 %
Washing Machines, AAA class	39-117 lt/load	0.6-0.8	65.6	40 lt/load	16,000 lt/year	40	12 %

Source: own elaboration based on multiple sources (Bio Intelligence Service and Cranfield University, 2009; BIO Intelligence Service, 2012; Cordella et al., 2013)

Table 5.3: Costs of different household water appliances and water saving devices

Water appliance/ saving device	***Marshallsay et al., 2007*** *(converteted from £ to €)*	***Cordella et al., 2013***
WC (toilet flushing)	82-337 €	
Taps	- 51 € (basic mixer tap has no water efficiency features) - 74 € (monobloc mixer tap with pop up waste and aerator) - 94 € (monobloc mixer tap with pop up and an Ecotop cartridge)	- 35-50 € (automatic shut off, push tap) - 160-450 € (example product with integrated aerators and flow regulators) - 210 € (tap with water breaks) - 750 € (water and energy saving tap) - 375 € (sensor tap, infrared mixer)
	- 10 € for attaching a water saving device (6€ for aerator & spray fittings that can be attached to existing taps, + 4€ for the adaptor)	- 5.5 € for a flow regulator - 25 € for ecobuttons
Shower, Bath	- electric shower: 174 – 225 € - mixer shower: 225 € (+157€ if a pump is added) - basic bath/shower mixer with hand shower attachment: 31-92 €	- aeration showerhead: 20-120 € - spray pattern/mechanism showerhead: 60-220 €
	18 € for attaching an aerated showerhead to a standard mixer shower 31 € for attaching a pressure reducing valves to a standard mixer shower	
Washing Machine	282-321 €, energy rating A 343-533 €, energy rating A+	
Dishwasher	233-429 €, energy rating A	
Rainwater Harvesting	2,451 € equipment cost + 288-429 € installation cost	
Greywater reuse	4,534 € initial cost + additional maintenance costs	

Source: own elaboration based on multiple sources (Cordella et al., 2013; Marshallsay et al., 2007)

5.2.2. Options for the agricultural sector

Agriculture is a key user in many basins. A significant proportion of irrigated land is supplied with water from irrigation projects of regional land reclamations units. The Directorates of Land Reclamation and the Departments of Ministries of Rural Development have relatively detailed data on cultivated land for each year, the crop type, water source, conveyance method and irrigation methods used. The above data can provide a very good picture of the status of irrigation in an area to be investigated, and can be subsequently used in the design of options for irrigation efficiency[1] increase. However, besides the areas of formal collective irrigation networks, additional self-supplied irrigated areas often exist. The main options for reducing irrigation demand are linked to decreasing losses and increasing the irrigation efficiency, i.e. conveyance and field application efficiency. This is mainly achieved by replacing open canals with closed pipes, by switching to drip irrigation and/or sprinklers from furrow irrigation systems, by implementing precision agriculture, and by applying deficit irrigation.

Replacing open canals with closed pipes targets to reduce canal leakage and increase conveyance efficiency. Water conveyance loss consists mainly of operation losses, evaporation, and seepage into the soil from the sloping surfaces and bed of the canal. Open channel networks are usually characterized by high levels of canal seepage, which lead to high water losses, and depends mainly on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals. In large irrigation schemes more water is lost than in small schemes, due to a longer canal system. From canals in sandy soils more water is lost than from canals in heavy clay soils. The losses in canals lined with bricks, plastic or concrete are very small. If canals are badly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost (Brouwer et al., 1989). Indicative values of conveyance efficiency in opens canals range from 60-80% for long (>2,000 m) to short (<200 m) sand earthen canals, from 70-85% for long to short loam earthen canals, from 80-90% for long to short clay earthen canals, and around 95% for lined canals (Brouwer et al., 1989). These values do not consider the level of maintenance, which, in case of bad maintenance, may lower these values by as much as 50%. Giokas et al., 2012 estimated that in Pinios area in Thessaly, Greece approximately 40%-48% of the irrigation water is lost when conveyed in canal systems, while less than half of those losses are estimated for piped systems.

[1] Irrigation efficiency is defined as the ratio of applied water that is beneficially used to the total amount of applied water (Canessa et al., 2011)

Conveyance losses in areas served by private works are certainly much less than losses in areas belonging to collective irrigation networks due to the fact that water is transported across a shorter radius from the source. For the Pinios area in Thessaly, Greece conveyance efficiency in closed pipes is around 80% in collective networks (Makropoulos and Mimikou, 2012), and 95% in small individual networks (Water Resources Management Consortium of Central & Western Greece, 2005).

Switching to drip irrigation and/or sprinklers from furrow irrigation systems targets to increase the field application efficiency. The field application efficiency mainly depends on the irrigation method, as well as on the level of the farmers' discipline. Irrigation water losses, illustrated include air losses, canopy losses, soil and water surface evaporation, runoff, and deep percolation. The magnitude of each loss is dependent on the design and operation of each type of irrigation system. Surface irrigation losses include runoff, deep percolation, ground evaporation and surface water evaporation (Rogers et al., 1997). Sprinkler irrigation losses include air losses (drift and droplet evaporation), canopy losses (canopy evaporation and foliage interception) and surface water evaporation (Rogers et al., 1997). Indicative values of the average field application efficiency are around 60% for surface irrigation (basin, border, furrow), 70% for sprinkler irrigation (traveling gun, center pivot, etc.), and 80% for drip irrigation (Brouwer et al., 1989). Lack of farmers' discipline may lower these values. Table 5.4 presents an overview of different literature values on the efficiency of irrigation methods. The values range, but in all cases it is demonstrated that, when considering single field irrigation efficiencies, sprinkler systems are generally better than furrows, and micro systems are generally the best. These trends are validated due to the following factors (Canessa et al., 2011):

- Both sprinklers and micro systems provide management with easier control of the total application than flood systems (provided there is a flexible water supply).
- Micro systems have better distribution uniformities than sprinklers, mainly due to the wind effects on overlap of sprinkler wetting patterns (note that linear sprinklers and center pivots will have generally higher irrigation efficiency ranges then standard field sprinklers and similar to micro systems, since one dimension of the overlap problem is negated by the continuously moving system).
- Sprinkler and micro systems tend to minimize deep percolation inefficiencies since the application rates are dependent on the system design and not the soil's infiltration rate.

In any case, attainable water application efficiencies vary greatly with irrigation system type, management practices and site characteristics. The analysis of the application efficiency of irrigation systems is thus important to identify potential places where improvements can be made and plan for interventions.

Table 5.4: Field application efficiencies of different irrigation methods

Authors / Methods	Solomon, 1988	Tanji and Hanson, 1991	Morris and Lynne, 2006	Rogers et al., 1997	Howell, 2003	Hanson et al., 1999	Sandoval-Soli et al., 2013
Surface irrigation							*Low/Mean/High*
Furrow	60-75	60-90	60-80	50-90	50-80	70-85	60/73/85
Furrow with tailwater				60-90			
Border	70-85	65-80	55-75	60-90	50-80	70-85	62/73/83
Basin	80-90			60-95	80-65		72/83/93
Sprinkler							
Hand-more or portable	65-75						60/70/80
Periodic move		65-80	60-75	65-80	60-85	70-80	
Continuous move		75-85		70-95	90-98	80-95	
Traveling gun	60-70						
Center pivot	75-90		65-90		75-98		70/80/90
Linear move	75-90		75-90		70-95		73/82/90
Solid set or permanent	70-80	85-90	70-85	70-85		70-80	70/78/85
Drip/Trickle							
Trickle (point source emitters)	75-90						
Subsurcface drip			85-95	70-95	75-95		77/86/95
Microspray			85-90		70-95		
Line source products	70-85						

Source: adopted from Canessa et al., 2011

Precision agriculture (PA) is a cultivation technique where both irrigation water and fertilizers are provided to the crop at optimum timings and doses. The practice has the purpose to sustain or even increase yields compared to the conventional cultivation ways. Numerous control technologies are available for optimizing irrigation such as evapotranspiration based controllers, soil moisture sensor controllers, and rain sensors

(Davis and Dukes, 2010; McCready and Dukes, 2011). The typical PA system works as follows (Evangelou and Tsadilas, 2012): infrared sensors are components of a wireless thermal monitoring system (Smart Crop) and identify the timing of application; soil moisture sensors back up the information for the timing while they evaluate the effectiveness of irrigation application, while an evapotranspiration sensor calculates the exact volume of water that has to be applied. Crop yields are also calculated and mapped for the purpose of estimating productivity and environmental performance indicators. All the above mentioned sensors/equipment are very easy to use, while yield maps and productivity indicators are able to demonstrate the sustainability of crop yields produced under this cultivation system and thus convince farmers for the usefulness of these technological innovations. Installation and testing of the PA technologies in the Pinios River Basin in Greece in selected pilot areas (representative of the diverse soil types, topographic features, evapotranspiration potential and farming community interests) was carried out in the framework of the European funded project HYDROSENSE (www.hydrosense.org). The technology was implemented for an entire cotton growth cycle period (May-September) and both, total water provided to the fields and cotton yields at the date of harvest were compared with those of neighbor fields managed with the traditional irrigation doses and timings. The results in the piloted fields showed that in two farms water consumption was reduced by 5-35% depending on the local conditions, while yields were increased up to 31%. On the other hand, in the 3rd farm occupied by clay-loamy soils, measurements in two different fields revealed that the 18% and 28% water reduction led to 10% and 18% yield reduction respectively. However, even in this case CWP (kg/m^3) increased by 5% compared to the baseline situation. Another interesting point is that nitrogenous fertilizers were reduced significantly (although detailed results are not available yet). Overall, the results of the PA experiments in the study area suggest that precision irrigation could reduce the irrigation water applied in cotton cultivations without negatively affecting harvest yields (Evangelou and Tsadilas, 2012). Precision irrigation and fertilization have considerable costs mainly because of the equipment needed to be installed and operated. One should also consider the cost for installing drip irrigation systems in those farms that are irrigated by different methods.

Deficit irrigation (DI) is defined as the application of water below the ET requirement, and is based on the concept that in areas where water is the most limiting factor, maximizing Crop Water Productivity (CWP) may be economically more profitable for the farmer than maximizing yields. For instance, water saved by DI can be used to irrigate more land (on the same farm or in the water user's community), which, given the high opportunity cost of water, may largely compensate for the economic loss due to yield reduction (Panagopoulos et al., 2012). The DI practice on the farm has been widely investigated as a valuable and sustainable strategy in dry regions, while the main advantages and disadvantages of this practice have been widely explored (Geerts and Raes, 2009). Fare and Faci (2009) have tested DI practices in two maize fields in northeast Spain and concluded that it was possible to maintain relatively high yields if small water deficits were limited to periods other than the flowering stage. In general, from a wide application of the practice it can be concluded that it seeks to stabilize, rather than maximize yields and this is usually achieved when water applications are limited to specific drought-sensitive growth stages of each irrigated crop.

5.3 Design and simulation of intervention curves

In order to implement the selected water saving measures in the urban and agricultural sectors, cost-effective "intervention curves" have been developed, which include more than one water saving measure. An optimization algorithm has been built and applied in Matlab in order to optimize the intervention measures' selection while minimizing costs, based on the prevously collected information on expected water savings and costs. The objective here was to maximize water saving while minimising the total cost (investement and operation/maintenance) by allowing a mix of measures under each sector (i.e. urban, agriculture). The Matlab programming environment has been used for developping relevant scripts and the NSGA-II algorithm has been employed in the optimisation. The procedure was successfully implemented, resulting in different mixes of measures for each sector, that can achieve various percentages of demand reduction under specific costs, as mapped by the results of the optimisation process.

5.3.1. The Urban Intervention Curves

Potable water is by definition water whose quality meets drinking water standards. Treating water to potable standards is an expensive and energy consuming process. However, as can be seen from Table 5.5 and Figure 5.1, only a small proportion (appr. 15–20%) of in-house water demand is actually used for purposes requiring drinking water quality (incl. water used for drinking, cooking and cleaning dishes). Water consumption patterns can vary significantly from house to house, depending on the household occupancy, the social and cultural conditions as well as on the type of the water consuming appliances installed in the houses (Memon and Butler, 2006).

Table 5.5: Water consumption share of different household micro-components in the industrialized world

Information Sources / **HH Micro-component**	***EU-wide overview***			***Country specific***			
	POST, 2000	*EA, 2007*	*Uihlein and Wolf, 2010 (across the EU)*	*EA, 2010 (in England & Wales for 2009-10)*	*Uihlein and Wolf, 2010 (for Greece)*	*EEA, 2001 (for Switzer-land)*	*Schleich, 2007 (for Germany)*
WC (toilet flushing)	31 %	30 %	25 %	26 %	25 %	33 %	32 %

Faucets	24 % *(of which 15% kitchen sink, 9% basin)*	20 %	30 % *(of which 5% for drinking and cooking)*	11 %	13 % *(5% for drinking and cooking)*	17 % *(3% for drinking and cooking)*	12 % *(3% for drinking and cooking)*
Shower	5 %	35 %	14 %	35 %	34 %	32 %	30 %
Bath	15 %		14 %				
Washing Machine	20 %	15 %	13 %	12 %	14 %	16 %	14 %
Dishwasher	1 %		2 %	9 %	8 %		6 %
Outdoor use	4 %		2 %	7 %	6 %	2 %	6 %
Miscellaneous use							
TOTAL	100 %	100 %	100 %	100 %	100 %	100 %	100 %
Rainwater Harvesting		Equivalent to: 25% toilet flushing, 25% clothes washing, 22.5% external tap use					
Greywater reuse		equivalent to 30% of the water consumed by toilets within the property					

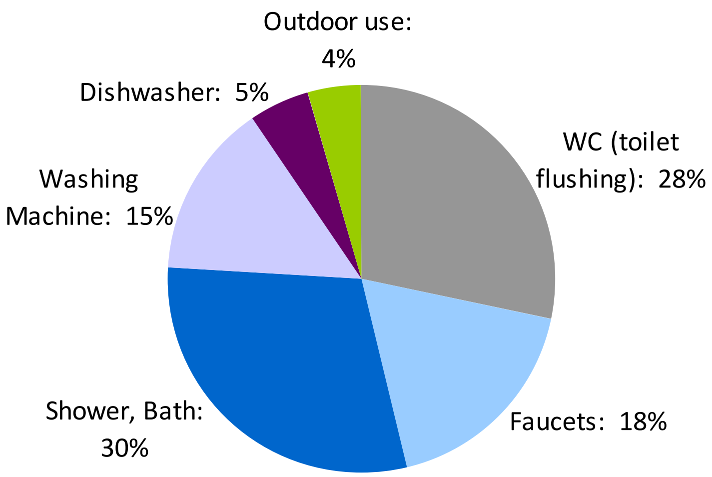


Figure 5.1: Average Water consumption share of different household micro-components in the industrialized world (based on Table 5.5)

For the design of the urban intervention curve, 7 water saving measures have been considered: istallation of dual flush toilets (1), retrofitting of low flow taps (2) and showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. Tier 1 measures comprise of dual flash toilets, low flow taps and showerheads, efficient washing machines and dishwashers, while tier 2 measures additionally include rainwater harvesting and domestic greywater reuse systems. The total potential water saving if applying all tier 1 measures (i.e. creating a “water efficient house”) is estimated to reach 46.5% of the total household consumption (Table 5.7). The application of additional tier 2 measures (rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier 1 measures in a “water efficient” house delivers an additional 16.2% saving, thus a total of 62.7% domestic water saving potential. In reality, since the rainwater harvesting and greywater reuse are expensive measures it is expected that a household would opt them after the tier 1 measures have been pursued. This assumption is considered in the calculations when building the urban intervention curve. For example, the influent to the GWR system (which originates from the showers/ baths and washing machines of the “water efficient house”) has been properly adjusted to account for the already achieved water saving of the tier 1 measures, and thus the influent potential volume has been accordingly decreased. As designed in the optimisation problem, the RWH performance is about 40% considering that only the rainy months can provide influent (roughly 4.8 months of the year in the area) and can feed this water for toilet flushing, washing clothes and outdoor use (garden irrigation, car washing, etc.). Respectively, GWR reuses the water coming from showers/baths and washing machines, and feeds this volume to toilets for flushing and outdoor use.

If all of the proposed tier 1 measures are applied in a household the total percentage of water saved is 46.5% per household, or 16.6% per capita (assuming an average household size of 2.8 persons), with a respective total cost of 1,550 € per household or 554 € per capita. If the additional tier 2 measures are applied, the total percentage of water saved is 62.7% per household, or 22.4% per capita (assuming an average household size of 2.8 persons), with a respective total cost of 7,550 € per household or 2,696 € per capita. Since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-10 years depending on the measure (as presented in

Table 5.6) has been considered in the calculations, while the OMC can be ignored. The resulting AEC for each measure is pesented in Table 5.6.

Table 5.6: Annual Equivalent Cost (AEC) of the urban measures based on a 7% discount rate and their years of useful life

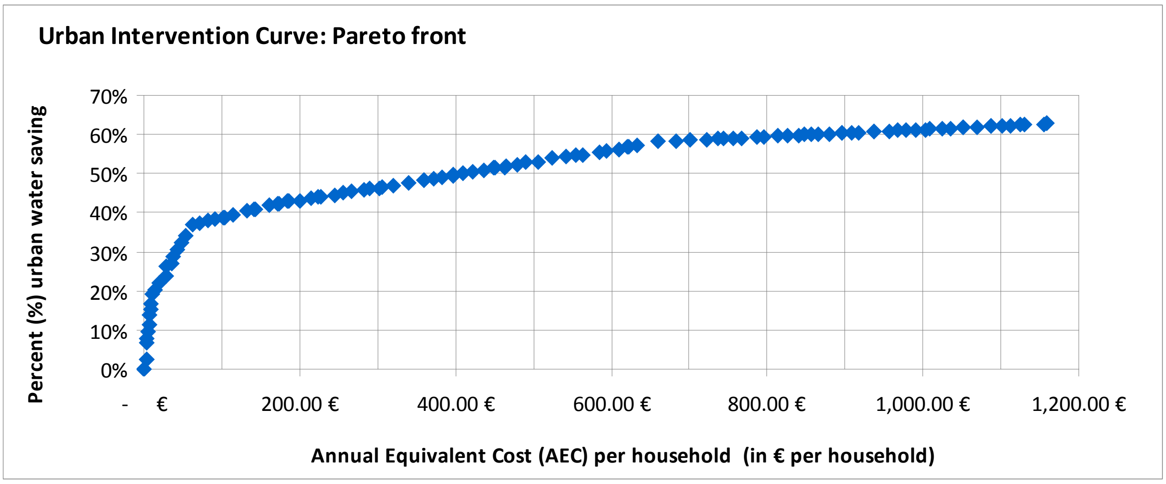
Water Saving Measure	Unit Cost €	r (discount rate)	n (useful life of the or measure in years)	AEC (€)
Dual Flush Toilet	170 €	0.07	7	32 €
Showerheads (1 item)	30 €	0.07	3	11 €
Low flow taps (2 items)	50 €	0.07	3	19 €
Efficient Washing machine	600 €	0.07	7	111 €
Dishwasher	700 €	0.07	7	130 €
Rainwater Harvesting	2,500 €	0.07	10	356 €
Greywater Reuse	3,500 €	0.07	10	498 €
TOTAL *per household:* *per capita:*	**7,550 €** 2,696 €			**1,158 €** 414 €

In order to design the optimum urban water cost-effective curve, a script has been developed in Matlab and an optimization was run. The Matlab Global Optimization toolbox was used which incorporates NSGA-II. The total number of households was divided into 5 clusters where different set of measures are applied in order to be able to capture a greater variability in the distributed solutions and their degree of penetration. The size of each of the 5 clusters is a decision variable and all 5 sum up to 67,956. Each cluster has 7 decision variables which are the 7 water saving measures discussed above. Therefore, the total number of decision variables is 7x5 clusters=35 plus 5 for the size of each cluster, a total of 40 variables. The population size was set to 15*numberOfVariables=600 and the maximum generation number to 2000. The cost-effectiveness parameters (i.e AEC and % expected water saving) that have been used in Matlab are shown below in the last two columns of Table 5.7. The objective function of the optimization was to maximize water savings while minimizing the AEC. The results of the optimization (Pareto front) are presented in Figure 5.2.

Table 5.7: Cost-effectiveness of water saving measures per household used in the design of urban "intervention curves"

Water Saving Measure	Performance (% water saving)	HH Micro-component targeted	HH Micro-component water consumption share (%)	Unit Cost €	AEC €	Expected water saving as % of total HH consumption

Tier #1	Dual Flush Toilet	40 %	WC	25 %	170 €	32 €	10 %
	Showerheads replacement (1 item)	60 %	Bath + Shower	34 %	30 €	11 €	20.4 %
	Low flow taps (2 items)	50 %	Faucets	13 %	50 €	19 €	6.5 %
	Efficient Washing machine	40 %	Washing Machine	14 %	600 €	111 €	5.6 %
	Dishwasher	50 %	Dishwasher	8 %	700 €	130 €	4 %
			Outdoor use (garden, car washing)	6%			
Tier #1 TOTAL				100 %	1,550 €	303 €	46.5 %
Tier #2	Rainwater Harvesting *(the effluent goes to: WC, washing machine, outdoor use of the tier #1 "water efficient" house)*	40 % (accounting the rainy months)	WC, washing machine, outdoors	29 %	2,500 €	356 €	11.6 %
	Greywater Reuse *(the influent originates from shower, bath and washing machines , i.e. the 22% of the tier #1 "water efficient house", and the effluent goes to WC and outdoor use)*	22 % *(potential influent from shower, bath and washing machine of the "water efficient" house)*	WC , outdoors	21 % (15% WC + 6% outdoors)	3,500 €	498 €	4.6 %
Tier #2 TOTAL				44 %	6,000 €	854 €	16.2 %
GRAND TOTAL					**7,550 €**	**1,158 €**	**62.7 %**



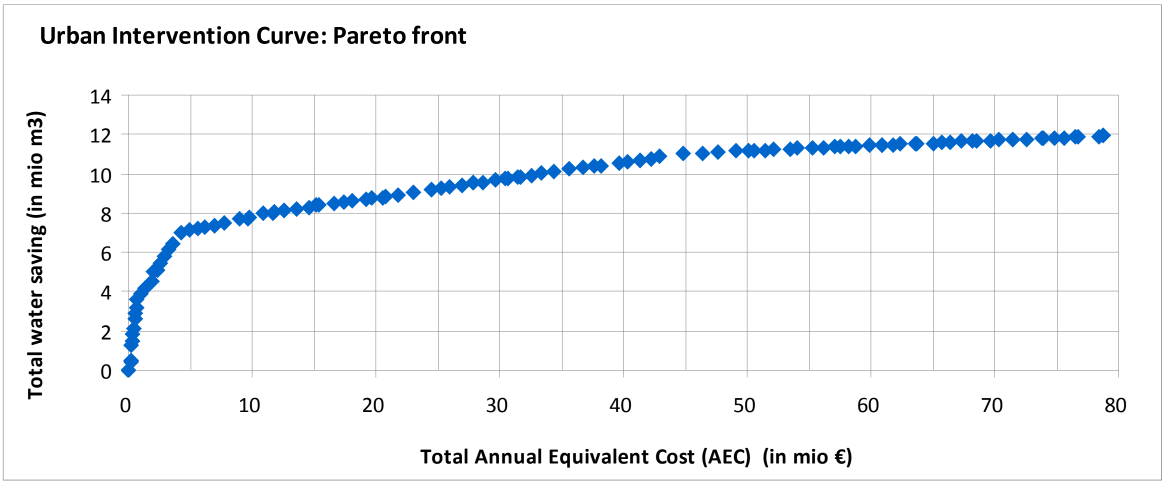


Figure 5.2: Cost-effective curve for the simulated urban demand management measures. *top*: percent water saving vs. AEC per household; *bottom*: total water saving vs. total AEC

As shown in Figure 5.2 above it is relatively easy and entails relatively low cost to achieve conservation up to 34% with a cost of approximately 53 €/household AEC (a total AEC of 3.6 mio €). Above that level of saving, and until the maximum level (62.7%) of water saving, the cost is increasing rapidly (as clearly depicted by the change of slope in the graphs of Figure 5.2) until the maximum cost of 78.7 million € per year. This is due to the algorithm selecting the relatively expensive measures of tier 2, such as rainwater harvesting and greywater reuse, as well as efficient washing machines of tier 1 to further decrease demand. Some indicative results of the optimization, which depict interesting solutions, are presented in Table 5.8 below. The full results are presented in Annex 3.

Table 5.8: Indicative results of the optimization for the urban cost-effective intervention curve

Water Saving %	AEC per HH €	Total water saving * (mio m³)	Total AEC mio €	€/m³ of water saved	*Penetration (% of the households adapting the measure)*						
					Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*RWH*	*GWR*
0 %	0 €	0	0 €	0.00	0	0	0	0	0	0	0
7.7 %	4 €	1.49	0.29 €	0.20	0	38%	0	0	0	0	0
20.4 %	15 €	3.93	1.00 €	0.26	13%	94%	0	0	0	0	0
30.4 %	43 €	5.87	2.92 €	0.50	100%	100%	0	0	0	0	0
32.4 %	48 €	6.24	3.27 €	0.52	76%	100%	66%	0	0	0	0
34.0 %	53 €	6.46	3.62 €	0.56	91%	100%	70%	0	0	0	0
36.9 %	62 €	7.12	4.22 €	0.59	100%	100%	100%	0	0	0	0
37.4 %	72 €	7.22	4.92 €	0.68**	100%	100%	100%	9%	0	0	0
38.0 %	83 €	7.32	5.61 €	0.77	100%	100%	100%	18%	0	0	0
38.4 %	91 €	7.40	6.16 €	0.83	100%	100%	100%	26%	0	0	0
38.7 %	102 €	7.47	6.97 €	0.93	100%	100%	100%	26%	9%	0	0
39.4 %	115 €	7.59	7.80 €	1.03	100%	100%	100%	37%	9%	0	0
40.4 %	132 €	7.80	8.98 €	1.15	100%	100%	100%	63%	0	0	0
40.7 %	142 €	7.85	9.65 €	1.23	100%	100%	100%	61%	9%	0	0
43.1 %	199 €	8.32	13.56 €	1.63	100%	100%	100%	89%	0%	9%	0
43.6 %	214 €	8.41	14.55 €	1.73	100%	100%	100%	89%	16%	9%	0
44.1 %	224 €	8.51	15.22 €	1.79	100%	100%	100%	100%	9%	11%	0
44.2 %	227 €	8.53	15.45 €	1.81	100%	100%	100%	100%	17%	9%	0
44.5 %	244 €	8.59	16.59 €	1.93	100%	100%	100%	89%	9%	20%	0
45.2 %	256 €	8.72	17.43 €	2.00	100%	100%	100%	100%	9%	20%	0
45.5 %	267 €	8.78	18.12 €	2.06	100%	100%	100%	100%	17%	20%	0
45.7 %	282 €	8.82	19.17 €	2.17	100%	100%	100%	89%	63%	11%	0
46.3 %	290 €	8.93	19.71 €	2.21	100%	100%	100%	100%	9%	18%	0
46.3 %	303 €	8.93	20.60 €	2.31	100%	100%	100%	89%	80%	11%	0
46.9 %	321 €	9.05	21.79 €	2.41	100%	100%	100%	89%	72%	18%	0
48.5 %	360 €	9.35	24.47 €	2.62	100%	100%	100%	100%	63%	29%	0
49.1 %	382 €	9.48	25.96 €	2.74	100%	100%	100%	100%	80%	29%	0
49.6 %	397 €	9.56	26.97 €	2.82	100%	100%	100%	89%	9%	63%	0
51.5 %	452 €	9.94	30.69 €	3.09	100%	100%	100%	100%	17%	72%	0
53.9 %	524 €	10.40	35.64 €	3.43	100%	100%	100%	100%	18%	93%	0
54.5 %	541 €	10.51	36.77 €	3.50	100%	100%	100%	100%	9%	100%	0
56.1 %	609 €	10.82	41.40 €	3.82	100%	100%	100%	80%	79%	100%	0
58.2 %	683 €	11.22	46.44 €	4.00	100%	100%	98%	100%	97%	100%	6%
58.5 %	701 €	11.29	47.63 €	4.22	100%	100%	100%	100%	100%	100%	8%
60.0 %	857 €	11.57	58.22 €	5.03	100%	100%	100%	100%	100%	100%	40%
61.3 %	1,004 €	11.82	68.21 €	5.77	100%	100%	100%	100%	100%	100%	69%
62.5 %	1,155 €	12.06	78.46 €	6.51	100%	100%	98%	100%	98%	100%	100%
62.7 %	1,158 €	12.11	78.73 €	6.50	100%	100%	100%	100%	100%	100%	100%

* The total water saving is based on the supply delivered in the Ali-Efenti case study in the dry year 2007 (which equals 19.29 mio m³), and has been calculated by applying the % saving on that value, in order to allow for some subsequent estimation of cost-benefit. Based on the study area and application this value is adjusted by the user.

** These values fall within the lower and upper bounds of the current total cost of water in the Ali-Efenti pilot area. This cost includes the financial, environmental and resource cost as estimated in the WFD River Basin Management Plan of the Thessaly RBD (Karavokyris et al., 2012).

The Business as Usual (BaU) represents the current situation, thus no measures are adopted, water saving is 0%, and the unmet demand remains at current levels. With a very low cost of less than 5 € AEC (specifically 4.3 €/household) a rough 8% saving of the urban water use can be achieved. This solution requires the installation of low-flow showerheads in 38% of the households in the area. A 20% saving can be achieved with an AEC of 15 €/hh and requires the installation of dual flush toilets in 13% of the households and low-flow showerheads in 94% of the households in the area. The total AEC in this case reaches 1 million € with a total water saving of 3.93 mio m^3, thus 0.26 €/m^3 of water saved. Respectively, with a cost of 0.56 €/m^3 of water saved (or AEC 53 €/hh) 34% of water can be saved (i.e. 6.46 mio m^3 in total). The latter requires the quasi-full penetration of low-flow showerheads and dual flush toilets (91%), and further introduces low-flow taps (2 items per hh) in 70% of the households. All optimization solutions beyond this level require the full penetration of these three measures (dual flush toilets, low-flow showerheads and taps) in all the households in the area. Also, beyond this level, the equivalent unit cost in €/m^3 of water saved fluctuates within the boundaries of common water costs, and eventually exceeds them (Figure 5.3). Thus, it is obvious that after some point the urban measures become too expensive, more than the actual cost of water.

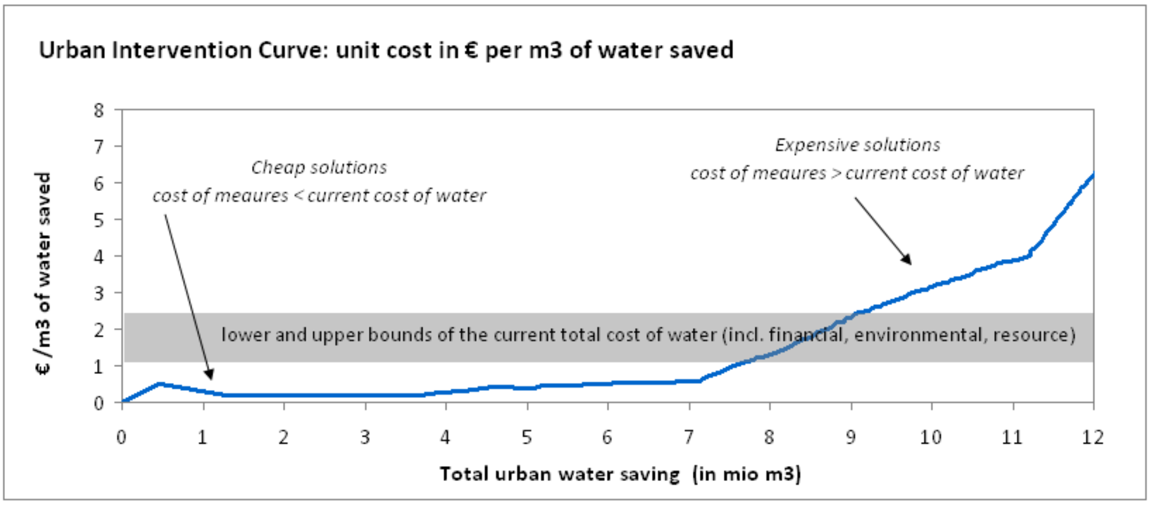


Figure 5.3: Cost-effective curve for the simulated urban demand management measures in €/m^3 of water saved

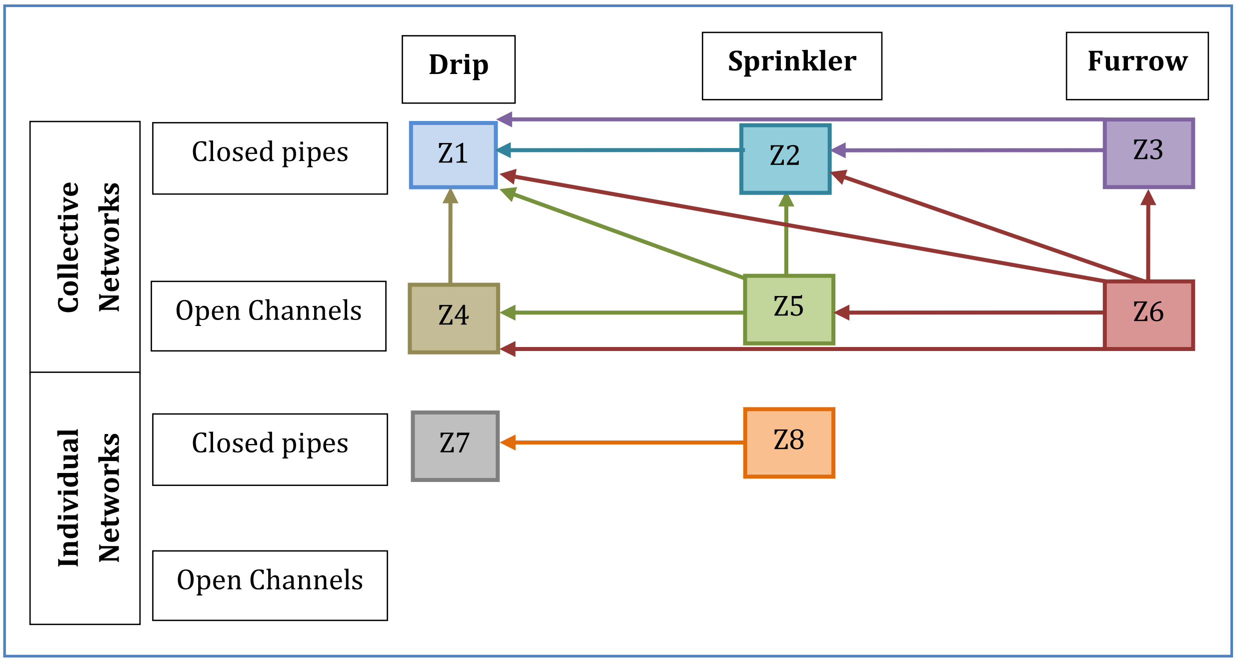
To further save water beyond the level of 37% additional tier 1 measures are gradually required, i.e. efficient washing machines followed by dishwashers, starting for a degree of penetration of 9% and gradually increasing. Two interesting solutions are observed at the range of 43% water saving, with an AEC of about 200 €/hh. These solutions require a unit cost of about 1.7 €/m^3 which is close to common cost of water. The algorithm in this case selects to introduce RWH systems at 9% of the households and restrict the penetration of dishwashers to either 0% or 16%. Similarly, in a following solution of 44.5% saving the RWH systems penetrate at a considerable level (in 20% of the households), while dishwashers are only placed in 9% of them. Above the level of 45.5% saving the unit cost of water saved is more than 2.1 €/m^3 and thus relatively expensive. To reach a 50% water saving (i.e. total of 9.56 mio m^3 water saved) the AEC per household reaches 397 € while the total investment sums up to 27 mio €. In this case RWH has penetrated in 63% of the households. In general we can observe that from saving ranging from about 50-55% the algorithm often favors rainwater harvesting over dishwasher installation. Greywater reuse systems are firstly introduced when all other measures have penetrated in all households, at a level of 6% securing 58% saving with an AEC of 683 €/hh (total saving: 11.2 mio m^3, total cost: 46.4 AEC mio €). Their degree of penetration gradually increases, with a subsequent increase in water savings and costs, up to full penetration with 62.7% saving and AEC 1,158 €/hh. This represents the maximum water saving potential of 12.1 mio m^3, with a total investment cost of 78.7 mio € per year, and a unit cost of 6.5 €/m^3 of water saved.

5.3.2. The Agriculture Intervention Curves

The cost-effective curve for irrigation investigates and tries to find the optimum trade-off between various conveyance and irrigation methods. In other words, the investigation focuses on how much the efficiency would be improved in an irrigated area, if a different "mix" of conveyance and irrigation methods is used, and which ones can potentially deliver the highest efficiency with the minimum cost. The following measures have been considered: converting from open channels to closed pipes, converting from furrow irrigation to sprinklers, converting from furrow irrigation to drip irrigation, converting from sprinklers to drip irrigation, applying precision agriculture (which also required the installation of drip irrigation systems if they do not already exist).

Similarly to the urban intervention curve design, a model in MATLAB was created and optimized in order to create the agriculture cost-effective intervention curves. In this model, the percentages that represent collective and individual networks in an area under investigation remain constant, while the decision variables used are the conveyance methods and the irrigation methods. Every transaction from one method (conveyance or irrigation) to another has a different effectiveness and a different cost. The transactions examined are only those which could improve the efficiency, i.e. the case of moving from closed pipes to open channels was not taken in to account. Figure 5.4 provides a schematic representation of the optimization. The transactions from one method to one other are subject of constraints and cannot exceed their initial value. The variables named "Z_n" represent the area which will be irrigated with the specific method. Also variables Z1 and Z7 have an extra variable Z9 and Z10 respectevily which represent precision irrigation (advanced, with minimum monitoring). The colored lines (purple, blue, red, green, bron and orange) represent the transactions. Note that each of them has different costs and benefits. To run the optimization, the Matlab Global Optimization was used which incorporates NSGA-II. The total decision variables are 15, one for each transaction and two for precision irrigation. The population size was set to 15*numberOfVariables=225 and the maximum generation number to 8,000.

Figure 5.4: Schematic representation of the optimization process



In order to run the Matrlab model, and obtain indicative curves, the area of Ali-Efenti catchment was used as a mockup. In this area the two main irrigation areas are within the Karditsa and the Trikala prefectures. In Karditsa prefecture about 20,420 ha are irrigated in total (21% through collective networks, 79% through small individual networks), mainly with sprinklers, while some drip and furrow methods are also aplied. In Trikala prefecture about 27,600 ha are irrigated in total (37% through collective networks, 63% through small individual networks), mainly with sprinklers, while some drip methods are also aplied. The combined irrigarion effiencies (starting values in the Matlab model) have been calculated to 75.4% for Karditsa and 77.6% for Trikala. Details are presented in Chapter 8, section 8.4.2. The irrigation efficiencies used in the Matlab model, for the combination of various conveyance and irrigation methods, are presented in Table 5.9. As seen, the small individual networks (closed pipes) which are drip irrigated have the highest efficiency and that is due to their conveyance efficiency being very high (95%). With regard to precision agriculture, it was assumed that it can only be applied to drip irrigation systems, so in case of a no-drip system conversion has been a pre-requisite. It was also assumed that PA contributes 10% in water saving. The various costs that can be inserted in Matlab, for converting from one method to another, are presented in Table 5.10 to Table 5.13, and have been defined after a detailed literature review. The user can select from and adopt these costs in the areas of interest.

Since all calculations should refer to a mean annual basis (Berbel et al., 2011) the Annual Equivalent Cost (AEC) is also calculated as follows:

$$AEC = \frac{r(1+r)^n}{(1+r)^n - 1} \times Inv + OMC$$

Where, Inv represents the investment costs, OMC are the operational and maintenance costs, r is the discount rate, and n is the useful life of the or measures. A discount rate of 7% and a useful life equal to 3-50 years depending on the measure has been considered in the calculations, while the OMC can be ignored.

Table 5.9: Aggregated values for irrigation efficiency (conveyance and filed application)

Irrigation Efficiency		Drip	Sprinkler	Furrow
Closed Pipes	Collective Networks	76.0%	68.0%	52.0%
	Small individual networks	90.3%	80.8%	61.8%
Open Channels	Collective Networks	57.0%	51.0%	39.0%
	Small individual networks	-	-	-

Table 5.10: Costs associated with increasing conveyance efficiency (converting from open channels to closed pipes)

Cost items	Cost per hectare (€/ha)
Total cost for moving from open channels to closed pipes	6,000
AEC (for a useful life n=50 years, and r=0.07)	435

Savings from slight yield increase of 2-4%	-37
Savings from energy bills (reduced pumping)	-8
Net total cost to converting to closed pipes (suggested for the Matlab model)	**390 €/ha**

Source: adopted from Panagopoulos et al., 2012

Table 5.11: Costs associated with converting from furrow to sprinkler irrigation

References/ Sources	Cost (€/ha)	Lifespan (yrs)	AEC (€/ha)
Payero et al., 2005	653	20	62
O'Brien et al., 1998; O'Brien et al., 2011	708	20	67
Amosson et al., 2011	989	20	93
Letey et al., 1990	1,043	12	131
Hoffmann and Willett, 1998	1,350	20	127
Dalton, 2004	1,660	20	157
Economic calculator for irrigation systems (EconCalc)	1,730	20	163
Coulton and Coutlon, 2010	2,160	20	204
Guilherme et al., 2015	2,500	20	236
Dalton, 2004	3,305	20	312
Average cost (suggested for the Matlab model)			**155 €/ha**

Table 5.12: Costs associated with converting to drip irrigation

References/ Sources	Cost (€/ha)	Lifespan (yrs)	AEC (€/ha)
Robertson et al., 2006	890	5.5	200
Payero et al., 2005	1,480	20	140
Letey et al., 1990	1,627	8	273
Amosson et al., 2011	2,135	20	202
Lower Arkansas Valley Water Conservancy District (LAVWCD)	2,669	20	252
Kazantzis, 2011	3,068	20	290
Economic calculator for irrigation systems (EconCalc)	3,720	20	351
Guilherme et al, 2015	4,000	20	378
Lamm et al., 2002; Economic comparison tool for Center Pivot and SDI	4,330	20	409
State of Queensland, 2011	5,400	20	510
Economic calculator for irrigation systems (EconCalc)	5,420	20	512
Lourmas et al., 2012	6,886	20	650
Average cost (suggested for the Matlab model)			**347 €/ha**

Table 5.13: Costs associated with implementing Precision Agriculture (PA)

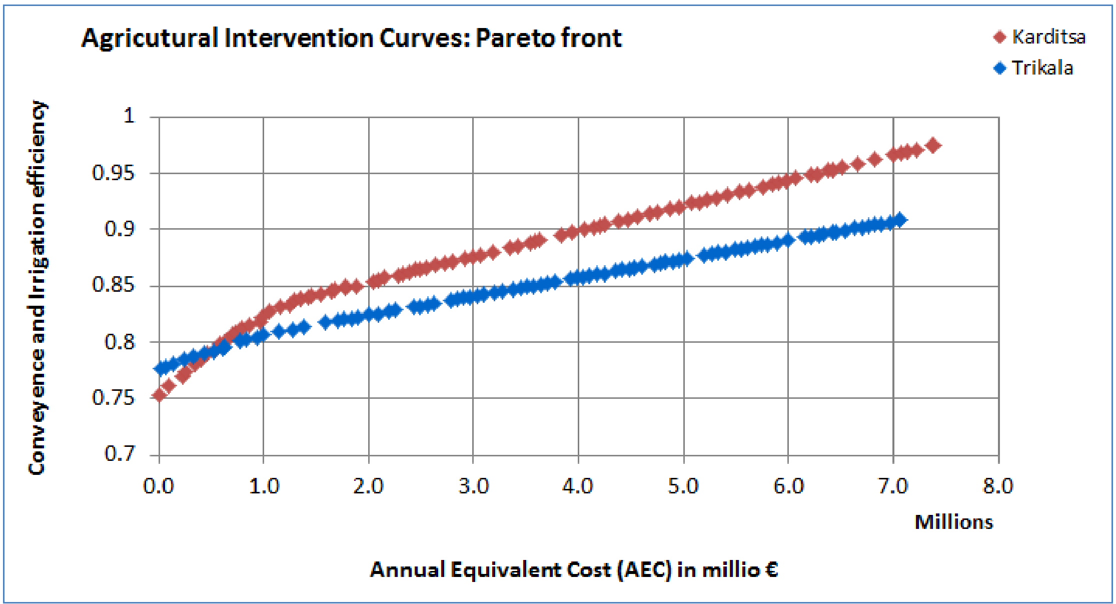
Cost items	Unit price (€)	Cost for 100 ha (€)	Cost per hectare (€/ha)
Yield monitor (1 item per 100 ha)	7,000	7,000	70
Soil moisture sensor (160 items per 100 ha)	35	5,600	56
Data logger (10 items per 100 ha)	200	2,000	20
Atmometer (10 items per 100 ha)	350	3,500	35
Sum of equipment cost		18,100	181
Drip irrigation modernization			650
Total cost for implementing PA			831

AEC (for a useful life n=5 years, and r=0.07)	202.67
Savings from reduced fertilisers' use (~30 kg N/ha)	-39
Savings from energy bills (reduced pumping)	-8
Net total cost for implementing PA (suggested for the Matlab model)	**156 €/ha**

Source: adopted from Panagopoulos et al., 2012

As an example, the developed cost-effective curves for Karditsa and Trikala prefectures are presented in Figure 5.5.

Figure 5.5: Karditsa and Trikala agricultural intervention curves



Overall, we can observe that depending on the initial irrigation efficiency of an area, and its existing mix of conveyance and irrigation methods, efficiency gains and increase potential range. With similar AEC, Karditsa's irrigation efficiency has the potential to increase more as compared to Trikala, although its original efficiency was slightly lower (75.4%). The increase in irrigation efficiency vs. cost is linear in Trikala, with a required AEC of about 400,000€ for each 1% efficiency gain. In the case of Karditsa we can observe a small break in the pareto curve: for efficiencies below ~82% an AEC of about 100,000€ is required for each 1% increase in the efficiency, while above 82% an AEC of about 250,000€ is required for each 1% increase in the efficiency. Still, these costs are lower than the ones required for Trikala, where the sprinkler irrigation heavily dominated (in closed pipes) and thus most solutions entail drip irrigation and PA. Each solution on the pareto curve is translated into a specific mix of measures, i.e. a new mix in the share of hectares that use a specific irrigation or conveyance method. The example of Karditsa is presented in the following Table 5.14. Note that a full list of the results is presented in Annex 3 (for both intervention curves). Overall, we can observe a clear correlation between the combined irrigation efficiency and the irrigation method used (sprinklers vs. drip irrigation): efficiency gains are clearly observed in as the area irrigated with sprinklers decreases and is replaced by drip irrigation systems, while the application of precision agriculture (in the areas irrigated with drip systems) further boosts efficiency.

Table 5.14: Optimization selected solutions, and associated changes in irrigation practices, for Karditsa

			Area (ha) irrigated with Collective Networks							Area (ha) irrigated with Individual Networks		
			Closed pipes				Open channels			Closed pipes		
Efficiency	**% change in eficiency**	**Cost (mio €)**	Furrow	Sprinkler	Drip	Drip with PA*	Furrow	Sprinkler	Drip	Sprinkler	Drip	Drip with PA*
0.754**	0%	0	0	600	386	0	686	2,101	515	15,970	161	0
0.770	2%	0.23	0	607	402	15	665	1527	1087	15949	182	30
0.774	3%	0.26	1	605	397	1	674	1388	1224	15960	171	17
0.793	5%	0.54	2	625	431	65	630	779	1,820	15,929	202	83
0.806	7%	0.70	1	605	397	1	674	1388	1224	15960	171	87
0.822	9%	0.70	1	605	397	1	674	1388	1224	15960	171	87
0.827	10%	1.06	1	634	847	173	197	235	2,373	15,918	213	63
0.845	12%	1.64	4	661	925	812	113	147	2439	15186	945	927
0.859	14%	2.29	4	661	927	797	110	145	2441	13882	2249	2142
0.868	15%	2.63	4	662	923	819	113	145	2,442	13,223	2,908	2,893
0.884	17%	3.35	4	662	927	823	108	144	2442	11802	4329	4303
0.890	18%	3.64	4	662	926	823	109	145	2442	11231	4900	4867
0.904	20%	4.25	4	662	927	820	108	144	2,443	10,003	6,128	6,085
0.919	22%	4.96	4	662	924	809	111	144	2442	8582	7549	7460
0.935	24%	5.63	4	662	926	828	108	145	2443	7271	8860	8802
0.943	25%	5.98	4	662	925	822	110	145	2,442	6,578	9,553	9,520
0.958	27%	6.66	4	662	927	830	107	144	2443	5217	10914	10872
0.975	29%	7.39	4	664	929	839	105	143	2,444	3,780	12,351	12,333

* The hectares where Precision Agriculture (PA) is applied are part of the hectares under drip irrigation
** It represents the baseline current scenario in the Ali-Efenti

5.4 Simulation of the intervention curves in WEAP21

It is suggested that the interventions curves developed in the previous chapter are simulated against a distributed physical-based water resources management models in order to assess their effectiveness on the system under investigation, and get an insight of the different trade-offs prior to decision-making. In the current research an investigation has been performed on how to simulate the urban and agricultural intervention curves in the Water Evaluation and Planning System (WEAP21[2]) software (SEI, 2001).

In order to simulate the urban intervention curve In WEAP21 a new user-defined variable "Water saving measures Coefficient (Wmu)" was introduced in the model. Wmu represents the percentage of water saved by applying the bundle of urban water saving measures of the intervention curve. Wmu can be inserted in the "Key Assumptions[3]" in the Data menu of WEAP and provides the user the flexibility to give this parameter a different value based on the percent urban water saving achieved from the intervention curve selected solution. The value entered in the model for Wmu must equal (100-% saving achieved)/100. For example, if a solution of the intervention curve has achieved 18% water savings, Wmu equals (100-18)/100 = 0.82. To calculate the final water demand, after the application of the measures, WEAP must be scripted to multiply the urban water demand (domestic, touristic, etc.) by the parameter Wmu. In the case that the urban water demand is simulated in WEAP as a function of population and daily use rates, the daily use rate can be directly multiplied by the Wmu. The following example is provided for the case that the user chooses to simulate the urban water demand using the "Annual Demand with Monthly Variation" method of WEAP. This option allows the user to express demands on an annual level. It requires inputting an activity level (e.g., number of people) and a water use rate associated with that activity level (e.g., an annual volume used per person). Monthly variation can then be

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[2] http://www.weap21.org/

[3] Under "Key Assumptions" a user can create and organize independent variables used to "drive" the calculations in your analyses. Driver variables are not directly calculated in WEAP, but they are useful as intermediate variables that can be referenced in the modeling calculations. It is very useful to create variables for all major modeling assumptions, especially those that will vary from scenario to scenario.

described either with some user-defined expression or variation weighted by days in each month.

For each domestic and touristic demand node, define in the Key Assumptions the following parameters:

Table 5.15: Key assumptions entered in WEAP21 to simulate urban water demand with the "specify monthly demand" method

Parameter	Value / Expression	Comments
Wmu	*(100-% Water Saving)/100*	The % Water Saving is obtained from the urban intervention curve
Water Use per capita	*Daily water use rate [m^3] * **Wmu***	The value of 0.17 m^3 can be used for the daily water use rate
Hotel/Motel use rate	*Daily water use rate [m^3] * **Wmu***	The value of 0.4 m^3 can be used for the daily water use rate of Hotels, and 0. 3 m^3 for Motels
Monthly Domestic Consumption	*20% of Monthly Domestic Demand*	It represents the % inflow consumed, lost from the system
Losses correction factor	*1.7*	This loss rate accounts for any distribution losses within each demand site (physical leaks, unmetered water use in public parks and buildings, etc.). The effect of distribution losses is to increase the supply requirement by this factor
Month Duration	*MonthlyValues(Oct, 31, Nov, 30, Dec, 31, Jan, 31, Feb, 28, Mar, 31, Apr, 30, May, 31, Jun, 30, Jul, 31, Aug, 31, Sep, 30)*	The duration in days of each month
Monthly correction factor	*October-March * 0.7 ; April-September * 1.3*	It is applied in order to provide a seasonal correction to the annual water demand (i.e. the water demand is higher during the dry period)

Then, define the following expressions for each urban demand node:

- *Monthly Domestic Demand (m3) = Population[cap] * Daily Water Use per capita[m^3] * Losses Correction Factor * Seasonal Correction Factor * Month Duration[day]*
- *Return flow = Inflow * (1-consumption)*
- *Tourism annual demand = Tourism_Nights spent[day] * Hotel Use Rate[m^3]*

- *Monthly Tourism Demand (m3) = Tourism_Annual Demand[m^3] * Tourism_Monthly Distribution Fraction * Losses Correction Factor*

In order to implement the agricultural intervention curve into WEAP21, the WEAP's key variable "Irrigation Efficiency Coefficient" can be used. Values obtained from the agricultural curve on the irrigation efficiency can be entered directly in this variable and influence the water supplied required per crop. An example is provided below when calculating irrigation needs based on the "Rainfall Runoff (simplified coefficient method)" method of WEAP. To model the irrigation water demand per node (site) the irrigation areas (m^2) must be incorporated in the catchment according to crop types (calculation of the areas occupied by each type of crop). Based on the Reference Evapotranspiration (ETref) and the crop coefficient Kc, the potential evapotranspiration PET_crop has been calculated for each crop type. Then, the irrigation need for each crop area can be identified based on the difference between the available precipitation and the PET_crop, and finally the required supply per crop can be determined by incorporating the irrigation efficiency coefficient. The total needs of the catchment are the sum of the individual needs and supply required for each crop. The above are described with the following expressions:

- *Define the irrigation area (m^2) occupied by each crop, the Kc for each crop and the Effective Precipitation (these values can be inserted in the "Key assumptions"*
- *PET_crop = Kc_crop * ETref*
- *Irrigation Need_crop = Max(0 ; (PETcrop[mm]-Available Precipitation[mm]))*
- *Supply Required_crop (m^3) = Area_crop [m^2] * Irrigation Need_crop[mm] / (1000*__Irrigation Efficiency Coefficient)__*
- *Supply Required_catchment (m3) = ΣSupply Required_crop (m3)*

5.5 Chapter Reference

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CHAPTER 6 - PRIORITIZING MITIGATION OPTIONS: OPTIMIZATION AND DECISION-MAKING

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6 PRIORITIZING MITIGATION OPTIONS: OPTIMIZATION AND DECISION-MAKING

6.1 Introduction to Decision Support Systems (DSS)

A Decision Support System (DSS) is described as "a system based on computer that supports the process of making decisions, helping to decide, to develop and to explore the implications of the decisions and thus to decide based on understanding" (French, 2000). Based on the reports of Sage (1993), French and Papamichail (2003), De Kok and Wind (2003), Koutsoyiannis and Efstratiadis (2003), we could refer that a DSS is a software application that consists of individual interconnected computational tools which all work together to assist those who make the decisions. The objective of DSS is an integrated approach to a decision problem, involving complex natural or artificial systems and weakly structured problems (not direct formulation of equations that describe them), so those who receive the decisions can understand the implications arising from alternative decisions. Characterized by interactivity, they enable users to extract useful information from raw data, and subsequently they assist those who make the decisions. They also facilitate the presentation and understanding of the results derived from each process through a user friendly environment which is often linked to a Geographic Information System (GIS).

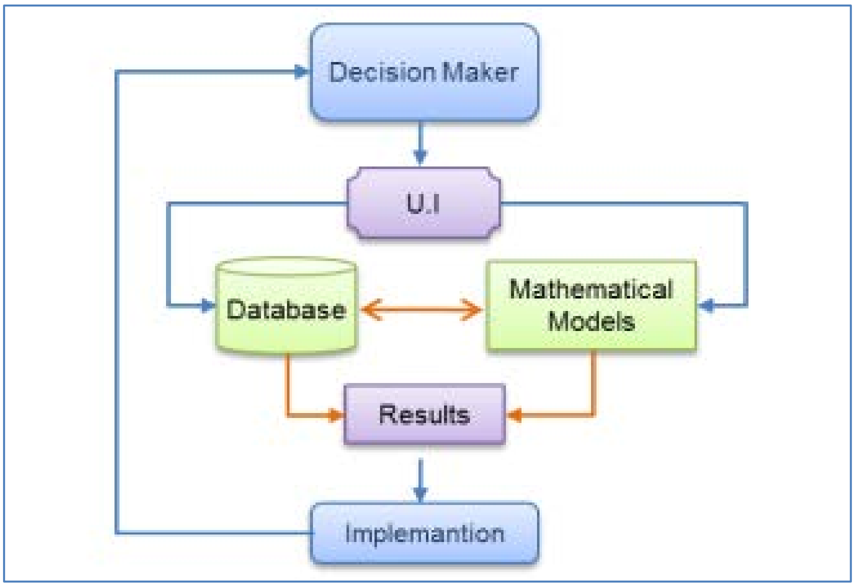

Figure 6.1: Conceptual Typical structure of a DSS

Source: Porto et al., 2003

The main challenges of a DSS are to analyze and forecast the future conditions, which are expected to dominate in the decision environment, to simulate the impact of the proposed alternative decisions, to evaluate the feasibility of decisions and to quantify the benefits and the cost based an evaluation criterion. The decision making process is completed with the evaluation and classification of the alternative decisions on the basis of the objectives set during formulation of the problem, in order to obtain the most advantageous decision with informed manner and take action. In a DSS the person who receives the decision has a basic role, since he develops the decision problem, sets the goals and determines the valuation of the alternative decisions. Finally, he is the one that evaluates the impact of yje alternative decisions, choosing the most effective and responsible action. Therefore, a DSS operates as a complementary tool during the decision process, but it doesn't indicate the decision. This is the basic differentiation of information systems that belong to the domain of "artificial intelligence". In the latter, the decision maker is substituted by an intelligent information system that indicates the decision based on engineering special knowledge or machine learning (French and Papamichail, 2003). According to Sage (1993), the DSS may be applied to a wide range of decision problems. The decision problems associated with the management of water resource systems fall into this category. Such problems are quite complex and comprise a significant number of factors that should be taken into account to consider an integrated approach. Thus, decisions related to these problems can benefit from the development and use of DSS. Such DSS, with significant acceptance and implementation at global level, is the MIKE HYDRO BASIN[1] (Danish Hydraulic Institute), the RIBASIM[2] (Delft Hydraulics), the MODSIM[3] (Colorado state University) and WEAP21[4] (Stockholm Environment Institute). In this work, the interest focuses on WEAP21.

[1] https://www.mikepoweredbydhi.com/products/mike-hydro-basin

[2] https://www.deltares.nl/en/software/ribasim/

[3] http://modsim.engr.colostate.edu/

[4] http://www.weap21.org/

6.2 Optimization as a Tool for DSS

6.2.1 Definition

Seeking the optimum solution of a problem, that minimizes or maximizes a function, a number of decisions (i.e. the decision variables) are evaluated with a performance measure (i.e. the objective function), while the decision variables may be subject to constraints. The domain of the function is called search space, while the value field is called evaluation space. In mathematics, optimization is defined as the procedure of identifying the extrema of a function. In particular, the process of identifying the total maximum or minimum of the function is known as global optimization, while the process of identifying a local extrema in a region of the feasible space is called local optimization.

6.2.2 Multi-Criteria Optimization

A common problem of water resources management is the existence of competing criteria that are measured in different units, therefore constituting the problem as multi-objective, and calling for a decision based on a multi-criteria optimization. The answer to this problem is given by an approach which implies the existence of multiple optimum solutions which are reflected to a common valuation field called Pareto front, where, the movement from one point to another of the front causes the degradation of performance of a criteria when another is improved. It is clear that optimization is a useful tool for DSS.

Assuming that the problem under study is developed for two conflicting criteria (i.e., water saving potential and cost of measures), then the feasible solutions can be represented as points in a two-axis graph, where each one is a solution with different performance measures. In Figure 6.2 these are presented as functions f1 and f2. In multi-objective optimization the concept of dominance between the various possible solutions is intriduced. This concept is represented in Figure 6.2. The blue sub-area above point A contains solutions worse than A for both criteria, that means that each of the solutions is dominated by A. The green points, on the left and right sides of point A, represent solutions indifferent to A because they may be better to one criterion, but they are worse to the other. The concept of domination allows characterization of certain solutions as optimal, according to the following definition: *"The point x * is optimal if there is no feasible point x which can improve objective f1, while not worse the objective f2"* (Efstratiadis, 2008).

The black points which are joined by the red line verify this definition. These point are, relatively to A, better for one criterion and worse for another (indifferent to A), while below them there are no points with better performance measures. The set of these points is called set of non-dominated solutions and represent the optimal "Pareto front". The points of the Pareto front are indifferent between them, and each one of them either dominates or is indifferent to any other feasible point of the search space. The purpose of multi-criteria optimization is to identify a representative number of non-dominated solutions to design the optimal Pareto front. Therefore, the optimization algorithm used in the process should have adequate characteristics to fully explore the search space and not get trapped in local extrema.

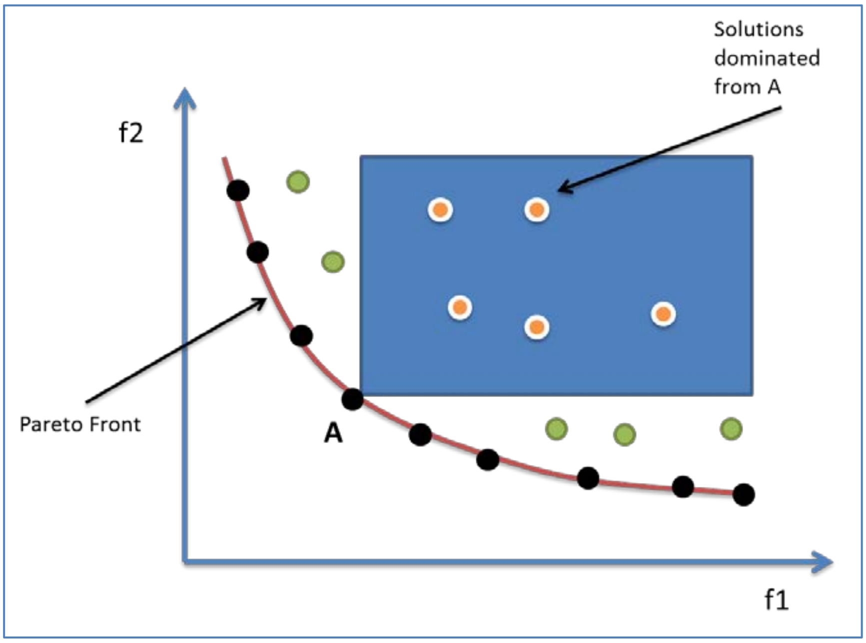

Figure 6.2: Pareto front of a multi-objective minimization problem

During the last decade there is an increased interest in algorithms that imitate nature. Some of the most widely used are Evolutionary Algorithms (EAs) and Genetic Algorithms (GAs), evolutionary programming, evolutionary strategies, local search methods and neural networks (Fu et al., 2010 ; Makropoulos and Butler, 2005a ; Makropoulos and Butler, 2005b). All the above belong to the scientific field of Artificial

Intelligence where the computer essentially imitates human nature. Evolutionary algorithms combine algorithmic schemes for the solution of real problems.

The first appearance of Genetic Algorithms (GA) goes back to early 1950 when several scientists from the fields of biology decided to use computers in their efforts to simulate complex biological systems. The systematic development, however, which led to the form in which it is known today, was made in early 1970 by John Holland (Holland, 1975) and his colleagues at the University of Michigan, in an effort to answer to problems based on the principles of valuation and heredity.

GAs are a mathematical optimisation method with broad application scope. The value of the method lies in its simplicity and its ability to be used effectively in various scientific fields like economics, chemistry, mathematics and engineering. The past 20 years have seen an extensive growth in the development and application of flexible and powerful GAs for solving environmental and water resources problems (Nicklow et al., 2010) due to their ability to solve nonlinear, nonconvex, multimodal, and discrete problems for which deterministic search techniques incur difficulties. The optimization techniques principles are based on natural selection and genetics (Goldberg, 1989). Genetic algorithms do not require knowledge or information concerning the slope of the search space, they are not affected by possible discontinuities in the search space, and they are very effective in large-scale optimization problems, in particular when the relevant functions have many extrema or discontinuous derivatives (Michalewicz, 1996). For multi-objective optimization in particular, where the solution is a multi-dimensional front (the pareto front), GAs have been developed that apart from the convergence to the optimal front, also ensure the conservation of an adequate spread of solutions on that front (usually based on a metric of their distance from each other).

6.2.3 Non-dominated Sorting Genetic Algorithms-II (NSGA-II)

One of the most popular, robust, efficient and fast multi-objective GAs is the Nondominated Sorted Genetic Algorithm (NSGA-II), developed by Deb and colleagues (Deb et al., 2002). In the current research work the NSGA-II, as coded in the MATLAB 7.10.0 (R2010a) GA toolbox (MATLAB, 2010), was used to drive the optimization process. The reason for this choice is that NSGA-II is a fast and elitist multi-objective algorithm, specifically designed to reduce computational complexity. NSGA-II is an improved version of the NSGA algorithm using a more efficient non-domination sorting algorithm, selecting an automatically sharing parameter, and making the Pareto-front by an implicitly elitist selection method (Deb et al., 2000). It is one of the five algorithms recommended for use in multi-objective GA problems by the state-of-the-art overview of such algorithms provided by Van Veldbuizen and Lamont (2000). The NSGA-II is widely used to solve the multi-objective problems in the engineering field (Deb and Jain, 2003; Deb and Raji Reddy, 2003), while applications using the NSGA-II in water resources engineering exist (Prasad and Park, 2004; Prasad et al., 2004; Reed and Minsker, 2004). The controlled elitism of NSGA-II always favors individuals with a better fitness value (rank). As the algorithm progresses, it maintains population diversity for convergence to an optimal Pareto front by using the options 'ParetoFraction' and 'DistanceFunction'. The first limits the number of individuals on the Pareto front (elite members) and the second is an embedded crowding distance function that helps to maintain their diversity by favoring individuals that are relatively far from each other, while this diversity is either calculated in function (phenotype) or in the design space (genotype), (MATLAB, 2010). The algorithm follows the traditional GA steps for optimizing a problem. It begins by creating a random or user-defined initial population. It then creates a sequence of new populations by performing individual ranking, selection, crossover and mutation.

6.2.4 Evolution of Species and Genetic Algorithms

The theory of evolution developed by Darwin in the middle of last century caused great inconvenience, since in conflict with the prevailing religious views on the origin of life. Over a century, the noise has not fully subsided, but the theory has been accepted by all scientists because it managed to convince and to provide satisfactory answers to fundamental questions. The purpose of this theory is to give an explanation for the phenomenon of life, its origins and basic functions. All this mechanism of natural selection seemed particularly attractive for John Holland, pioneer in GAs in the early '70s. Holland imagined that some ideas and features of the nature could have results if incorporated into computer algorithms to get new efficient techniques to solve complex problems. The result of this work was the evolution of a new and promising technique in optimization (Georgopoulos et al, 1999). Given that the basic idea behind the GAs is the imitation of the mechanisms of nature, the main points of the theory of evolution of species related to the GAs are:

- There is no objective basis for segregation in living organisms, superior and inferior. In each biological species, some individuals leave more offspring than the others and so inherit reproductive characteristics of successful people are increased in the next generation. The difficulties, obstacles, and adversities that occur during the life of organisms are the factors that determine which of them will manage to survive and multiply. Thus, by changing the environment and living conditions the populations change their characteristics and try to adapt each time in order to ensure their survival.
- The change which occurs in the characteristics of people is the change of their chromosomes, which are complicated organic molecules that encode the structure and the characteristics. Chromosomes are composed of smaller parts, known as genes. The set of genetic information that is encoded in the genes is called genotype. The creation of a new organization includes the decoding of chromosomes. The decoded content of a given chromosome is called phenotype. Major features of the phenomenon of evolution are the crossover and mutation.
- During the mutation a random change in chromosome structure takes place, sometime copying biological molecules or by exogenous factors (e.g. radiation), as a direct result of having a characteristic change. The mutation may cause improvements and, without doubt, some mistakes were a major factor in the progressive evolution of life.
- The product of reproduction is a new organization, whose chromosomes consist of genes derived from the parents. Thus, the characteristics of the new organization are derived from parents' genes. The gene that ultimately determines the attribute is called dominant and the other recessive.

6.2.5 The Anatomy and Basic Content of a typical GA

A typical GA for a given problem is composed of the following five components (Michalewicz, 1996; Lykothanasis, 2001):

- A genetic representation of the potential solutions of the problem.
- A way to create an initial population of possible solutions.
- A fitness function - evaluation, playing the role of environment, classifying its solutions based on their fitness.

- Genetic functions which alter the composition of the offspring.
- Values for the various parameters used by the genetic algorithm, like population size, probabilities of genetic operators, etc.

A typical GA starts with an initial population which is comprised by chromosomes. The solutions from the initial population are used to form a new population. The motivation of this procedure is the hope that the new population will be better than the old one. The solutions which are selected to form the new population (offsprings) are selected according their fitness. This is repeated until satisfying the stopping criteria which could be for example the time or convergence. A typical GA executes the following procedure:

1. Generate random population on *n* chromosomes (within the search space)
2. Evaluate the fitness function *f(x)* of each chromosome
3. Create new population by applying genetic functions which are presented below:
    a. **Selection**: Select two parent chromosomes from the initial population (the better fitness, the bigger chance to be selected)
    b. **Crossover**: Using a crossover probability, cross over the parents to form a new offspring (children). If no crossover was performed, offspring is an exact copy of parents.
    c. **Mutation**: Using a mutation probability, mutate new offspring at each locus (position in chromosome).
    d. Create the new population **based on the offspring** produced.
4. Recalculate the fitness function with the new population
5. Repeat this procedure until the stopping criteria are met

It is obvious that selection, crossover, and mutation are important parts of a GA, and the performance of the algorithm is mainly influenced by these operators. The parameters to be optimized are generally represented in the form string to adjust more easily the genetic procedures. The mode of representation plays an important role in the accuracy and the computation time of a genetic algorithm, and the usual mode of representation is binary, that is strings composed of two elements, 0 and 1. The number of symbols in the series is called the length of the string. The representation may also be made using vector integer or real numbers, with each integer or real number representing a parameter (Lykothanasis, 2001). At the beginning of the optimization process, genetic algorithms require a set of initial solutions, meaning the creation of an initial population.

This can be done in two ways, either by creating random solutions with a random number generator (this happens when the search space is unknown) or knowing the search space of the optimal solution when it leads to less time. The objective functions have the role of the environment by evaluating the solutions and the constraints of the problem in terms of adaptability. When the constraints are critical and must not be violated, the solutions which violate constraints can either be rejected from the beginning or have a penalty in their score depending on the design.

- **Selection**

Based on the evolution theory, the chromosomes with the best fitness function will survive and create offsprings. There are many methods to choose the best chromosomes: the roulette wheel with uneven intervals, the choice depending on the rank (competition-tournament) Boltzman selection, the steady state selection, the elitism etc. The roulette wheel selection, the rank selection and the elitism are described here.

According to the roulette wheel selection, the valuations of the values are expressed by the intervals of an imaginary roulette (Figure 6.3). The individuals for the next generation are selected from a random rotation of the wheel. It is obvious that the probability of selection is proportional to the range/width of the interval, and consequently the value of the individual. Every individual will statistically reproduce as many times as the corresponding ratio of its value to the total value of the population. So the individual with the greatest value will create more offsprings. However this method presents problems if the fitness differs very much, i.e. if a chromosome has very high fitness relatively to the others, then the other chromosomes will have very few chances to be selected. According to the tournament (rank) selection method, each individual produces a certain number of offspring according to the classification of the fitness function. With this method all chromosomes have a chance to be selected.The idea of elitism consists in preserving the best chromosome (or few of the best) to the new population. Elitism can increase the performance of the GA because it maintains the best found solution.

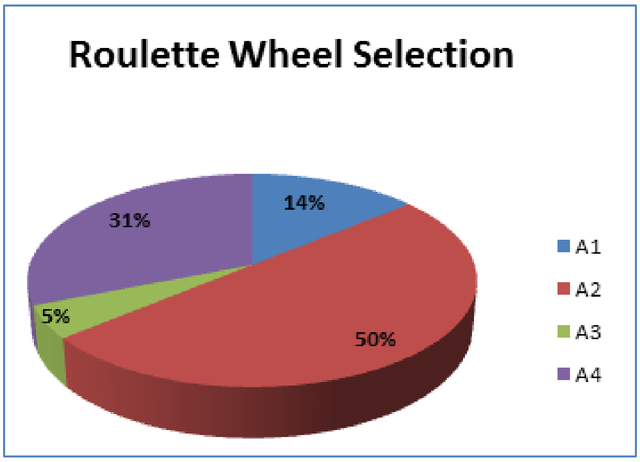

Figure 6.3: Roulette wheel selection.

- **Crossover**

It's a simple operation (genetic operator) of exchange of genetic material between two individuals (parents) of the population mated randomly creating two new chromosomes. Its aim is to include in the new generation that will emerge after application, individuals who are different from their parents and will bring together the best characteristics. Some methods that are used are the single point crossover, the two point crossover, the uniform crossover (where bits are randomly copied from the parents), and the arithmetic crossover (where some arithmetic operations take place to make a new offspring). An example of single point crossover is presented below. Binary string from beginning of chromosome to the crossover point is copied from one parent, the rest is copied from the second parent.

Parent A	Parent B	Offspring
1100**011**	**0011**001	**0011011**

- **Mutation**

Mutation acts as a safety valve for cases where the selection or the crossover possibly lead to a local optimum. It is random in nature, and may be advantageous or non-advantageous to the person in the race for survival, in contrast to natural selection, which is based on the law of probability. The mutation can occur in any gene of any chromosome.

The operation of a GA is graphically summarized in Figure 6.4. The factors controlling a GA are the population size and crossover, and the mutation probabilities. There have been several studies to determine the influence of these factors on the performance of GAs. The main conclusions are:

- A large population size increases the computation time of each iteration but also increases the probability of convergence
- The crossover rate determines the frequency of crossover. A small rate may slow down the convergence of the algorithm and a large rate may lead to local optimum.
- Regarding the possibility of mutation, large values introduce high diversity in the population which can cause instability. On the other hand, it is usually difficult for a GA to find the optimum solution with a very small percentage of mutation..

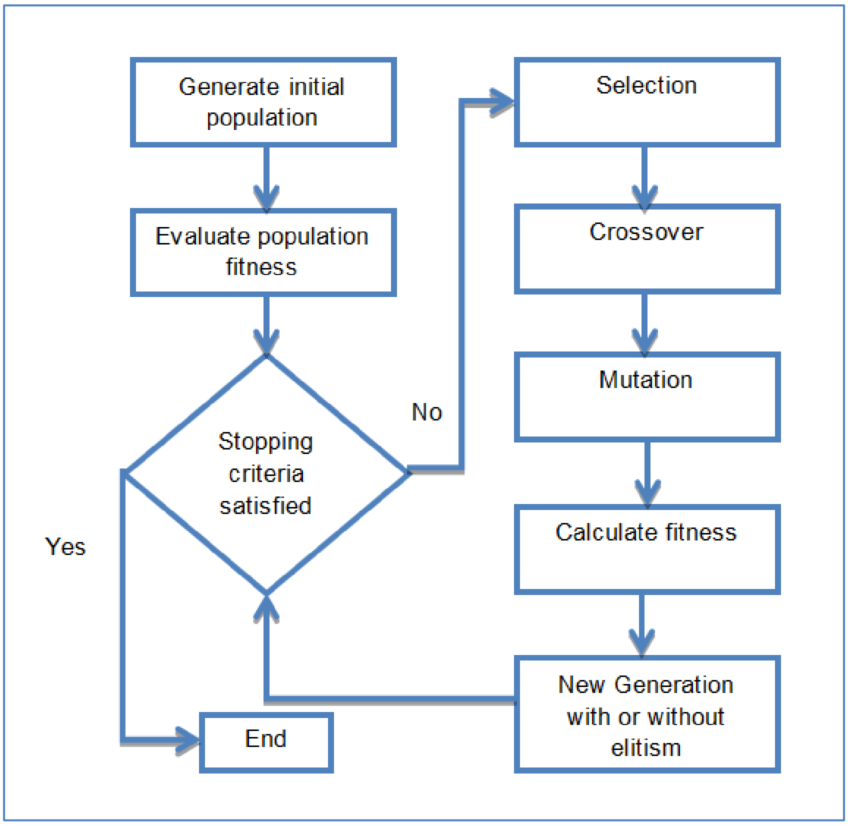

Figure 6.4: Typical GA flowchart

6.3 MOEA in Water Resources Management

Evolutionary algorithms have been widely applied in water resources management problems, and GAs are among the most used. Labadie (2004), Baltar (2007), Nicklow et al. (2010) and Adeyemo (2011) present a comprehensive review of GAs applications in water resources management systems. Suen et al. (2005) applied NSGA-II in the Dahan River Basin in Taiwan for multi-objective analysis. The objectives analyzed were the demand for urban water supply, and the preservation of the downstream minimum flow (ecological flow). Tang et al. (2005) reviewed the application of evolutionary algorithms for the calibration of hydrologic models, considering multiple objectives. Makropoulos, C. and Butler, D. (2005a) focused on the development and use of such a hybrid EP algorithm to solve a particular multi-objective spatial object-location problem. The domain knowledge which forms part of the heuristics of the methodology developed is provided by the problem of citing sustainable water management strategies within the urban fabric, taking into account social, economic, technical and cost parameters and constraints. Reis et al. (2005e, 2006) applied GAs in combination with linear programming for operation of a reservoir system considering multiple objectives. Kim et al. (2006) applied NSGA-II algorithm to a system of multiple reservoirs (3 in cascade) for the optimization of two conflicting objectives of the Han River basin. Three different scenarios were analyzed. In this study the penalty function was used to consider the constraints of the problem. Reddy e Kumar (2007) applied a multi-objective Differential Evolution Algorithm for the optimization of a water resource system. The comparison was made with NSGA-II. The application of this case study was done on a single reservoir system with a period of 12 months of simulation, and the objectives were to meet demand for irrigation and hydropower generation. Baltar (2007) applied Multi-objective PSO and NSGA-II to a series of problems related to water resources management, including a simple reservoir system. Regulwar et al. (2010) applied a Differential Evolution (DE) algorithm for optimal operation of a single reservoir used for hydropower generation and irrigation. The constraints imposed to the problem were the maximum flows for hydropower generation, the maximum irrigation flow, the reservoir volume limitations and the monthly balance equation. Tsoukalas and Makropoulos (2005) applied multi-objective obimization using the NSGA-II to define the optimum management of multi-reservoir system on Nestos in Northern Greece, develop optimal operational rules for the hydrosystem and assess the impact (and potential benefits) from the construction of the third reservoir.

6.4 The Optimization Scheme and Process

6.4.1 Overview of the optimization process

The purpose of the global optimization is to find the optimum mix of measures to be applied so that the optimization objectives are minimum. The main tools used for the optimization are the WEAP21 model to simulate the hydrosystem, and Matlab to optimize it. A bespoke code, handing the interaction between the two programs, was developed in Matlab using the COM-API available in WEAP21. That interaction makes possible the bi-directional cooperation of both programs and utilizes of Matlab toolboxes. This process was followed successfully in an earlier study for the modelling and calibration of the hydrosystem of Nestos in Northern Greece (Tsoukalas and Makropoulos, 2013). Figure 6.5 presents a flow chart of the simulation-optimization process. The main loop of the iterative process begins with the transformation of the decision variables into an appropriate format readable by WEAP21. Then, the connection to the WEAP opens through COM-API, WEAP21 reads the variables and calculates the results, and the results are then exported to Matlab where the objective functions are calculated. If the optimization criteria are met the process ends, or else the loop runs again until convergence with the criteria is achieved.

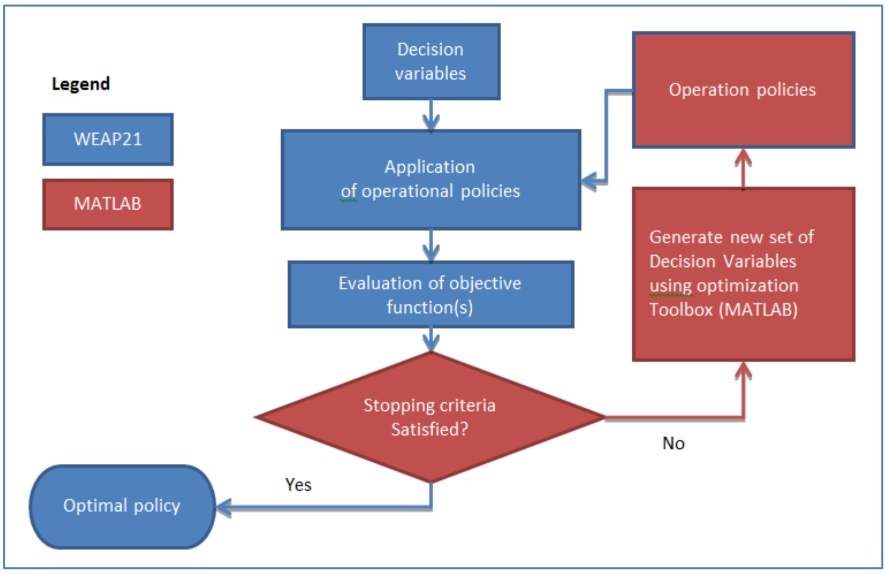

Figure 6.5: Flow Chart of the methodology used to optimize the hydrosystem

The structure of the Decision Support System (DSS) proposed here is based on the Parameterization-Simulation-Optimization (PSO) framework (Koutsogiannis and Economou, 2003) which was recently extended to handle multiple objectives (Tsoukalas and Makropoulos, 2015). Among the advantages of the PSO, as compared to other similar methods such as the implicit and explicit stochastic optimization, is the parameter-parsimonious character. In the current research, the following steps, consistent with the PSO methodology, have been followed:

1. Representation of the main hydrological components by using simulation models
2. Parsimonious parameterization of the demand management measures (interventions) via a small number of decision variables
3. Definition of appropriate objective function(s) that express the desired performance metric(s).
4. Simulation of the hydrosystem under different scenarios by implementing the parameters (variables) that define the interventions (i.e. suggested demand reduction policy)
5. Utilization of an optimization algorithm to define the optimum mix of interventions across the urban and agricultural sectors (i.e. derive the best management policy)

The proposed DSS is comprised of three main components, as illustrated in Figure 6.6:

(a) The intervention curves which simulate the cost-effectiveness of optimum bundles of urban and agricultural measures (as developed previously in Chapter 5) which can be considered as a "Library";

(b) The WEAP21 model, which is the "Simulation Engine", used to evaluate the impact and effectiveness of the measures on the physical-based reality under different scenarios, and estimate the yields and market values of the crops, and

(c) The MATLAB-GA, which serves as the "Optimization Engine", used for the selection of the mix of measures across the urban and agricultural sectors in order to minimize unmet demand with the minimum AEC.

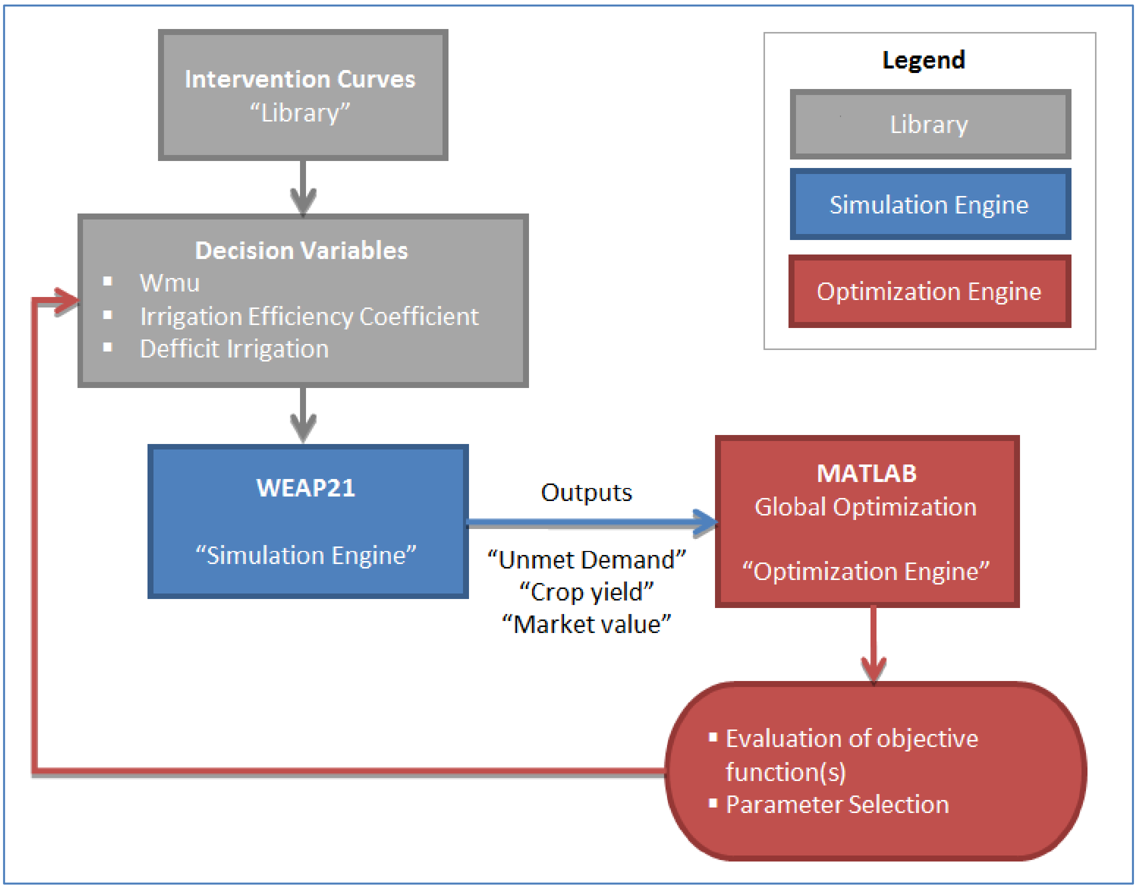

Figure 6.6: Schematic representation of the components of the developed DSS

6.4.2 Parametrization and Simulation: Decision variables and their simulation in WEAP21

The decision variables used in the global optimization process are the "Wmu" (representing the urban intervention curve), the "Irrigation Efficiency Coefficient"[5] (representing the agricultural intervention curve), and the "Defficit Irrigation". These decision variables are obtaining their values from the developed intervention curves (Chapter 5), which already resulted from an optimization process, and thus the search space of the solutions is already reduced, making the overall approach parsimonious and less time-consuming.

As previously discussed in Chapter 5, in order to implement the urban cost-effective into WEAP21, a user-defined variable (Wmu) was used in the simulation. Wmu represents

[5] In the mock-up model of the Ali-Efenti two different irrigation efficiency coefficients, each one representing the Karditsa and Triakala intervention curves respectively (as explained in Chapter 8). Thus, in this case we had 2 decision variables associated with the agricultural interventions.

the percentage of water saved by applying urban water saving measures, and its values are obtained as output of the Matlab optimization process. Similarly, in order to implement the agricultural intervention curve, the WEAP's default variable "Irrigation Efficiency Coefficient" was used in the simulation. The irrigation efficiency coefficient values are also obtained as output of the Matlab optimization process. In case that the various WEAP irrigation nodes are grouped under more than one irrigation section, then multiple "irrigation efficiency coefficients" can be used, but it is generally recommended grouping of the nodes under larger sections to apply similar classes of "irrigation efficiency coefficient" where relevant. Finally, to implement deficit irrigation in WEAP, a user-defined variable (DefIrr) was introduced. This variable ranges between 0%-30%, and is used to limit the capacity of transmissions links. If DefIrr is 30%, the maximum flow is limited to (100%-DeffIrr) = 70%. Thus, the supplied water transmitted via the transmission links will be reduced by 30%. This decrease in supply delivered, due to deficit irrigation, implies a decrease in crop yield with a consequent reduction in the farmers' income, i.e. there is a cost associated with deficit irrigation burdening basically the farmers (indirectly through the loss of potential income). This cost is taken into account in the optimization objective function, as well as in the simulation process, by introducing into WEAP data on crop yields as a function of water decrease and market price of crops. The equations below are used by WEAP21 to obtain the actual yield and the market value respectively. In below the values indicative of Ym, Ky, as well as producer prices that have been used for specific crops (alfalfa, maize, cotton, sugarbeets, orchards, kiwi, aloe vera, broccoli)

$$Y_a = Y_m \cdot (1 - K_y \cdot (1 - \frac{ET_a}{ET_c})) \quad (1)$$

Market Value = Y_a * Area * Price (2)

Where:

Ya = actual yield (corresponding to ETa) [kg/ha],

Ym = maximum theoretical yield (corresponding to ETc) [kg/ha],

ETa = actual crop evapotranspiration,

ETc = potential crop evapotranspiration,

Ky = yield response factor to water stress,

Market Value = Total market value for crop [€], Area = cultivated area [ha],

Price = unit market price for crop [€/kg]

Table 6.1: Data introduce in WEAP to calculate farmers' income changes

Crop	Potential Yield (Ym) (Kg/m²)	Producer Price (€/Kg)	Yield response factor to water stress (Ky)*
Alfalfa	1.360	0.190	1.10
Maize	1.037	0.185	1.25
Cotton	0.280	0.474	0.85
Sugarbeets	6.110	0.027	1.00
Orchards	1.800	0.400	1.30
Aloe vera	5.25	0.571	1**
Broccoli	1.87	0.842	1**
Kiwi	1.633	0.524	1**

*WEAP21 Crop library (FAO Irrigation and Drainage Paper No. 33, Doorenbos and Kassam, 1979)
**Assumed equal to 1 due to lack of data. Ky=1: yield reduction is directly proportional to reduced water use.

6.4.3 Optimization algorithm and Objective functions

The MATLAB 7.10.0 (R2010a) software is used as the "Optimization Engine" for the selection of the mix of measures across the urban and agricultural sectors in order to minimize unmet demand with the minimum AEC. A controlled, elitist GA, that is a variant of NSGA-II, as coded in the MATLAB GA toolbox (MATLAB, 2010), was used to drive the optimization process. Alternatively, other algorithms can be used from the Matlab suite. The controlled elitism always favors individuals with a better fitness value (rank). As the algorithm progresses, it maintains population diversity for convergence to an optimal Pareto front by using the options 'ParetoFraction' and 'DistanceFunction'. The former limits the number of individuals on the Pareto front (elite members), while the latter is an embedded crowding distance function that helps to maintain their diversity by favoring individuals that are relatively far from each other, while this diversity is either calculated in function (phenotype) or in the design space (genotype) (MATLAB, 2010). The algorithm follows the traditional GA steps for optimizing a problem. It begins by creating a random or user-defined initial population. It then creates a sequence of new populations by performing individual ranking, selection, crossover and mutation.

The total decision variables of the current optimization problem are three, one for each cost-effective curve (urban and agriculture) and one for deficit irrigation. The population size and the maximum generation number used are the default ones define in Matlab, thus 15*numberOfVariables=45 population size, and 200 maximum generation number. These values result in a total of 45*200 = 9,000 runs. These values can be adjusted depending on the complexity of the problem and the computation time that the simulation model requires (case and model dependent). For example, in the case of the Ali-Efenti case study the maximum generation number was set to 100 (i.e. 4,500 runs) since each run required about 10 minutes. It is suggested to run two distinct optimization scenarios since deficit irrigation is associated with an indirect cost to the farmers through income losses (due to reduced yields), while the remaining agricultural and urban interventions' costs are associated with capital investments which usually burden the governments. Deficit irrigation can reduce unmet demand under the assumption that the farmers accept to demand less water under a specific cost. That cost is calculated as a change in farmers' income. Hence, it is a policy question if applying deficit irrigation in an area is a socio-economically acceptable option. Running two optimization scenarios, one without DeffIrr as a decision variable and another incorporating DeffIrr, provides a wider selection of options to the decision-makers and planners. While these two scenarios have different decision variables they have the same performance measures. The objective functions used in the two optimization scenarios are presented below. These objective functions concern unmet demand. They can be formulated to include the total unmet demand, or focus on a specific problematic sector, e.g. agricultural unmet demand in case this is the predominant one in the area (which is often the case since domestic is usually priority No1, and has a high reliability).

<u>Optimization scenario #1:</u>

Objective 1: MIN ($\sum$ *Agricultural Unmet Demand)*

Objective 2 : MIN ($\sum$ *AEC Investment Cost - Farmers' Income Change)*

Note that in this case the decision variable "*Deficit irrigation*" is not taken into account.

<u>Optimization scenario #2:</u>

Objective 1: MIN (*Σ Agricultural Unmet Demand)*

Objective 2: MIN (*Σ AEC Investrment Cost - Farmers' Income Change)*

Note that in this case the decision variable "*Deficit irrigation*" is taken into account.

The optimization process starts with the initialization of a population either randomly, by the GA or by the user. Each individual of the population consisted of genes equal to the number of decision variables (in this case equal to 3: Wmu, Irrigation Efficiency Coefficient, DeffIrr). The values of genes of an individual form the genotype, while their real representation (phenotype), represent a combination of measures, and are real numbers from the intervention curves. To ensure that the algorithm creates only valid solutions (individuals), lower and upper bounds (LB and UB) need to be defined for each decision variable so that the GA is driven to select values from the appropriate space. The upper and lower bounds for the Wmu and the Irrigation Efficiency Coefficient are directly obtained from the intervention curves. For the Wmu these are 0% and 62.7%, while for the Irrigation Efficiency Coefficient they equal the current and maximum potential efficiencies respectively. For example, for the case of Karditsa and Trikala used in Chapter 5 they range from75.4% to 97.5% and 77.6% to 90.8% respectively. These boundary constrains in each chromosome gene are the only mathematical constraints of the optimization problem in this case.

Once appropriately formulated, the individuals of the population are evaluated against to the objective functions (as defined above for each scenario), which are the unmet demand on an annual basis and the costs associated with the interventions. The algorithm tries to minimize the performance criteria (i.e. the objective functions) through an iterative process of population evolution. After the evaluation of the population, the algorithm compares the generation number with a maximum generation counter, defined as the termination criterion. If the current generation number is equal to the maximum, the algorithm stops, otherwise the population undergoes selection and genetic operations (crossover, mutation) in order to form a new population for the next generation. The higher the population size and the number of maximum generations, the better the convergence to the optimal Pareto front, but the higher the computation time of the process.

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CHAPTER 7 – INTERNALIZING DROUGHT RISK MANAGEMENT: DEFINITION OF POLICY TARGETS AND IMPLEMENTATION

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7 INTERNALIZING DROUGHT RISK MANAGEMENT: DEFINITION OF POLICY TARGETS AND IMPLEMENTATION

7.1 Overview

The final step of the DRM mainstreaming process aims at deriving indicative targets for reducing the vulnerability of the system under investigation, translating them into sectoral policy action, and internalizing them, along with the selected mix of measures, into local and national action plans and development frameworks. As such, a stepwise approach must be implemented with the following consecutive activities: proofing the selected interventions, setting and negotiating targets, reaching an agreement, internalizing them in development frameworks, implementing them by creating the preconditions and enabling environments, and finally monitoring and updating them. To achieve this process the following steps are proposed, as detailed in Table 7.1.

Table 7.1: Overview of the sequential phases for internalizing and implementing DRM

Phase	Main Activities
"Proofing phase":	Development of future climate change and socio-economic scenarios (drawing on EU and/or regional accepted scenarios) with input from stakeholders. Testing the robustness of the optimization results under these future scenarios (against the baseline) and evaluate whether the proposed interventions can maintain their overall performance under future conditions.
"Designing phase":	Negotiation and definition of policy targets: Explore trade-offs between the optimal robustness-proof solutions in a transparent participatory way, accounting for local specificities and priorities, and identify indicative Policy Targets per sector.
"Integration phase":	Internalize Drought Risk Management (DRM) into development frameworks: definition of entry points, initiation of instruments and mechanisms to internalize the targets, draft suggestions how to implement DRM in action plans, development programmes, etc., identifying the necessary preconditions and enabling mechanisms.
"Implementation phase":	Implementation of the policy targets by national, regional and/or local governmental bodied

"Evaluation phase":	Measuring progress towards the targets, policy impacts and effectiveness: monitor and disseminate the impact of the DRM mainstreaming using suitable indicators.

7.2 Proofing phase: Robustness analysis under future scenarios

The definition of concrete policy targets, that can be sustainable on the medium to long-term, requires the assessment of the robustness and sensitivity of the selected risk management options and measures under a set of alternative scenarios. Some solutions may be found to be more robust under changing climatic and/or socio-economic conditions, while others may be more sensitive as depicted in Figure 7.1. A robustness analysis is thus essential in guiding the definition and selection of policy targets. In this section, some existing well-established methods and tools for simulating future climate and socio-economic conditions, necessary to the analysis of robustness, are presented.

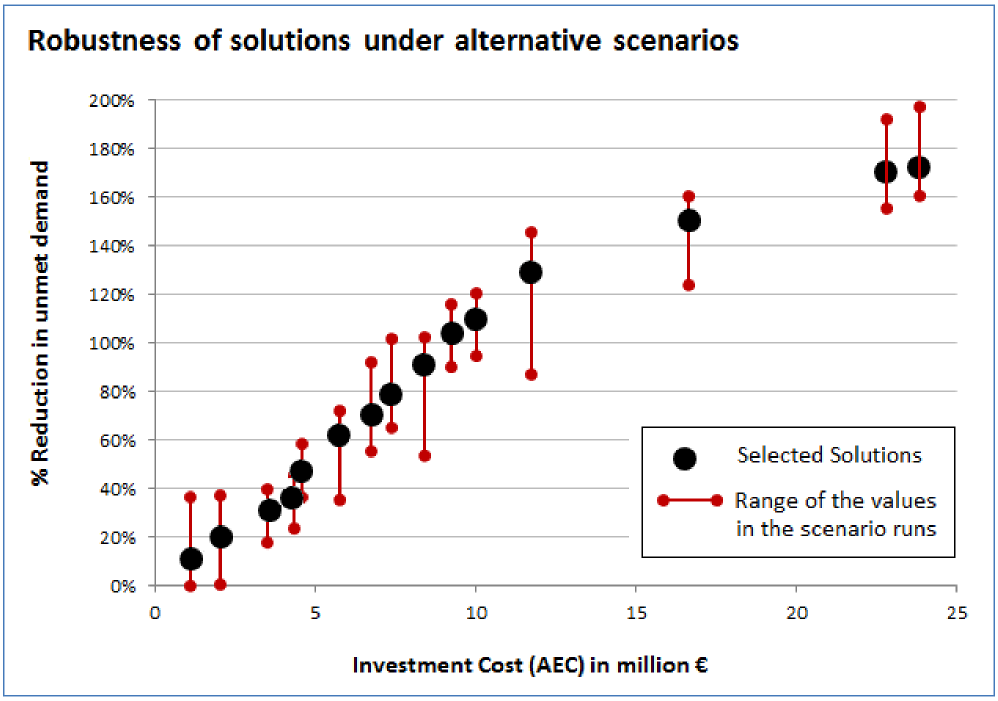

Figure 7.1: Overview of the steps for internalizing DRM.

7.2.1 Climate Scenarios

Climate change in IPCC (Intergovernmental Panel on Climate Change) refers to a "change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer" (IPCC, 2007). It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

This definition differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (UN, 1992).

To provide input for evaluating climatic and environmental consequences of alternative future GHG emissions, and subsequent mitigation and adaptation options, IPCC developed a set of emission scenarios[1] (Houghton et al., 1990; Leggett et al., 1992; Pepper et al., 1992), which represent images of the future, or alternative futures. They are neither predictions nor forecasts. A set of scenarios assists in the understanding of possible future developments of complex systems (IPCC, 2007). Most recently the SRES scenarios have been developed as described in the IPCC Special Report on Emissions Scenarios (IPCC, 2007), building on the previous efforts. They cover a wide ranges of the main driving forces of future emissions (demographic, technological, economic developments), and are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces. The SRES scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. No likelihood has been attached to any of the SRES scenarios. Based on the IPCC Emission Scenarios Special Report (IPCC, 2000):

- The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century (8.7 billion) and declines

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[1] Storyline: a narrative description of a scenario (or a family of scenarios), highlighting the main scenario characteristics and dynamics, and the relationships between key driving forces.

Scenario: projections of a potential future, based on a clear logic and a quantified storyline.

Scenario family: one or more scenarios that have the same demographic, politico-societal, economic and technological storyline. Source: IPCC TGICA, 2007.

thereafter (7 billion by 2100), and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

- The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population (15 billion by 2100). Economic development is primarily regionally oriented, and per capita economic growth and technological change are more fragmented and slower than in other storylines.
- The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.
- The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

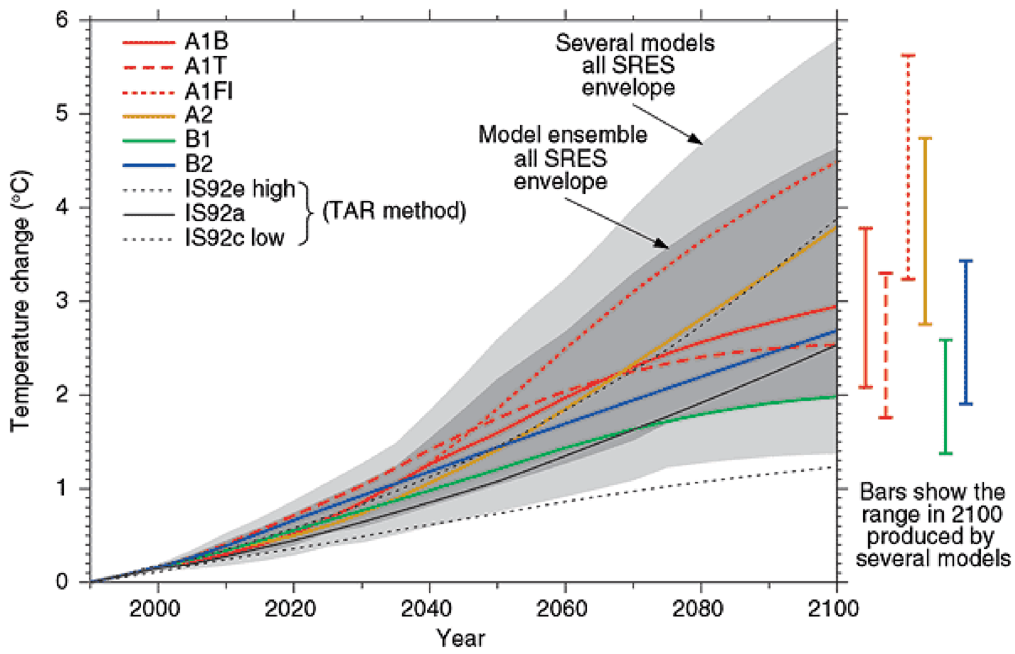

Figure 7.2: Global mean temperature projections for the six illustrative SRES scenarios[2]

Source: IPCC, 2001

A summary of the characteristic of these scenarios is presented in Table 7.2 below:

Table 7.2: Overview of the characteristics of the IPCC SRES scenarios A2, B1, A1B

Scenario Group	A1B	A2	B1	B2
Population Growth:	Low	Low	Low	Medium
GDP Growth:	Very high	Very high	High	Medium
Energy Use:	Very high	High	Low	Medium
Land Use Change:	Low	Low	High	Medium
Oil/Gas Resource Availability:	Medium	Medium	Low	Medium
Technological Change:	Rapid	Rapid	Medium	Medium
Change Favouring:	Non-Fossil Fuel	Non-Fossil Fuel	Efficiency & Dematerialisation	dynamics as usual

Commonly, studies conducted in the framework of EU research projects and elsewhere, consider in their future climate simulations the IPCC SRES scenarios A2 (moderately

[2] The projection is using a simple climate model tuned to a number of complex models with a range of climate sensitivities. For comparison purposes, following the same method, results are shown for IS92a. The darker shading represents the envelope of the full set of thirty-five SRES scenarios using the average of the model results (mean climate sensitivity is 2.8 °C). The lighter shading is the envelope based on all seven model projections (with climate sensitivity in the range 1.7 to 4.2 °C). The bars show, for each of the six illustrative SRES scenarios, the range of simple model results in 2100 for the seven AOGCM model tunings. Source: IPCC, 2001.

free trading environment with rapid innovation and high turnover of capital and some concerns about environmental sustainability), B1 (world of increased concern for environmental sustainability) and A1B. The following EU project have delivered projections of climate change scenarios based on regional downscaled Global Circulation Models (GCM) and Regional Circulation Models (RCM), that are available for use to researchers, and can be provide a basis for simulation future climate in areas of interest. The PRUDENCE carried out a series of 30-year simulations of current and future climate with four high resolution atmospheric general circulation models (AGCMs). The spread of the AGSM simulations was defined from the IPCC scenarios A2, B2. The responses in these experiments were analyzed to determine the confidence in the differences of the driving AGCM simulations as well as the reliability in the fine scale details of the RCM simulations. The CRU domain, on which total monthly and seasonal fields from all RCM and stretched-GCM runs exist, has a regular 0.5x0.5 degree grid. The PRUDENCE project ended in 2004. The next EU-financed major effort in regional climate modelling was the ENSEMBLES project, financed under Framework Programme 6. A major archive of data in 25km resolution covering the transient periods 1951-2100 or 1951-2050 according to the SRES A1B scenario is available (data from the PRUDENCE and ENSEMBLES are available at: http://prudence.dmi.dk/public/DDC/ and http://ensemblesrt3.dmi.dk/) The added value of these bias corrected datasets relies on the fact that the ensemble prediction system for climate change is based on the principal state-of-the-art, high resolution, Global and Regional Earth System Models developed in Europe, validated against quality-controlled, high-resolution gridded datasets for Europe, and has produced for the first time an objective probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer time-scales. ENSEMBLES ended in 2009, and was followed by the project CORDEX, which is an international WCRP project (World Climate Research Programme) without funding. The CORDEX archive is set up in the ESGF infrastructure known from CMIP5 and is still growing (updated 2015/08/19). Another EU project, the WATCH project, evaluated how the global water cycle and its extremes respond to future drivers of global change (including greenhouse gas release and land cover change). WATCH has produced a large number of data sets which should be of considerable use in regional and global studies of climate and water. The data are all hosted by IIASA in Austria on a basic FTP site available to the public. For an introduction to the water cycle with illustrations of decadal averages plus visualization of available data, see www.waterandclimatechange.eu. An outline of the WATCH available data is presented below (http://www.eu-watch.org/data_availability):

- WATCH Forcing Data 20th Century: a meteorological forcing dataset (based on ERA-40) for land surface and hydrological models (1901-2001). Five variables are at 6 hourly resolution and five variables are at 3 hourly resolution.
- WATCH-Forcing-Data-ERA-Interim: WFDEI was produced post-WATCH using WFD methodology applied to ERA-Interim data. It is a meteorological forcing dataset extending into early 21st C (1979 – 2012). Eight meteorological variables at 3-hourly time steps, and as daily averages.
- WATCH Driving Data 21st Century: similar to the WATCH forcing data but for the 21st Century and is constructed from model output not interpolated observational data. Two climate scenarios, B1, A2 and a Control were each run through three global climate models (CNRM, ECHAM5 and IPSL) to produce a total of 9 sets of future driving data at 0.5 degree resolution.
- WATCH 20th Century Model Output Datasets: the WATCH forcing data has been run through nine land surface or global hydrological models, to produce a range of output variables.
- WATCH 21st Century Model Output: the 21st century WATCH driving data was put through ten land surface and global hydrological models.
- 20th Century Ensemble Data: ensemble of model output data from 5 models for 4 hydrological variables, stored as daily data in monthly netCDF files
- Test Basin data: 21st C driving data for each test basin (Crete, Glomma, Nitra, Upper-Elbe, Upper Guadiana)

It has to be notice that the SRES scenarios, as well as the downscaling processes with the RCMs are not free for uncertainty. In general, there are three types of uncertainty: in quantities, uncertainty about model structure, and uncertainties that arise from disagreements among experts about the value of quantities or the functional form of the model (Morgan and Henrion, 1990). Sources of uncertainty could be statistical variation, subjective judgment (systematic error), imperfect definition (linguistic imprecision), natural variability, disagreement among experts and approximation (Morgan and Henrion, 1990). Funtowicz and Ravetz (1990) distinguish three main sources of uncertainty: data uncertainties, modeling uncertainties and completeness uncertainties.

Future climate can also be evaluated using stochastic simulation. Long time series of precipitation and temperature can be generated following a stochastic modelling approach, based on the statistical properties of the historic time series. When generating synthetic time series of hydrological processes at sub-annual scales, it is important to preserve seasonal and annual characteristics, short-term persistence and over-year scaling behavior (hurst). Langousis and Koutsoyiannnis (2006) proposed a methodology that directly operates on seasonal time scale, avoiding disaggregation, and simultaneously preserves annual statistics and the scaling properties on inter-annual time scales. Two specific stochastic models were proposed: a simple, widely used seasonal model with short memory to which long-term persistence is imposed using a linear filter, and a combination of two sub-models, a stationary one with long memory and a cyclostationary one with short memory. Both models are tested in a real world case and found to be accurate in reproducing all the desired statistical properties and virtually equivalent from an operational point of view. The CASTALIA v.6.1 (2008) (Efstratidis et al., 2005, Efstratiadis et al., 2014) software is a computer system for stochastic simulation and forecasting of hydrologic processes, and can be used for the purpose of deriving stochastic timeseries. It includes procedures for simulation of the long-term hydrologic persistence of multivariate processes on annual scale, cyclostationary (periodic) stochastic models, and disaggregation procedures for the simulation on monthly scale. In addition, it includes procedures for the estimation of vector and matrix parameters based on optimization techniques. It is appropriate for symmetric and asymmetric distribution functions and it preserves the coefficients of skewness of variables.

Bootstrapping is an alternative to classical parametric methods of statistical testing such as the t-test, chi-squared test, etc. The two principal advantages of the proposed bootstrapping are that no assumptions are made about the distribution of the datasets being compared, and the methodology is intuitive and relatively simple to understand. The original data (control) will be resampled with replacement enough times to produce unbiased results in a comparison. “Resampling with replacement” involves using a random number routine to select numbers arbitrarily from the original data and employing these as substitute data in whatever statistical procedure is required. The process can be repeated, say 1000 times, to give representative results and confidence in the estimated changes (Mudelsee and Alkio, 2007).

7.2.2 Socio-economic Scenarios

The SRES emission scenarios, and their underlying narratives (Table 7.3), have been a basis for the creation of different global and regional socio-economic change scenarios. The latter attempt to capture relevant demographic, social, economic, technological and environmental lines of development, related to different levels of GHG emissions and underlying assumptions of the SRES. As the SRES storylines assume that no specific climate policy is implemented, they form a baseline, against which the socio-economic scenarios (with specific adaptations and mitigation measures) can be compared (Fruhmann and Jager, 2010).

Table 7.3: Summary characteristics of the storylines used in the IPCC SRES scenarios

	A1B	A2	B1	B2
World:	Market-oriented	Differentiated	Convergent	Local solutions
Economy:	Fastest per capita growth	Regionally oriented; lowest per capita growth	Service and information based; lower growth than A1	Intermediate growth
Population:	2050 peak; then decline	Continuously increasing	2050 peak; then decline	Continuously increasing at A lower rate than A2
Governance:	Strong regional interactions; income convergence	Self-reliance with preservation of local identities	Global solutions to economic, social, and environmental sustainability	Local and regional solutions to environmental protection and social equity
Technology:	Balanced across all (energy) sources	Slowest and most fragmented development	Clean and resource-efficient	More rapid than A2; less rapid and more diverse than A1/B1

Source: Carter et al., 2007

An example of global socio-economic scenarios, which are widely used for multiple purposes are the four GEO-4 scenarios (UNEP, 2007). They have been developed through a stakeholders' participatory approach and explored the interplay between some of the environmental issues in atmosphere, land, water and biodiversity. They are based on assumptions related to institutional and socio-political effectiveness, demographics, economic demand, trade and markets, scientific and technological innovation, value-systems and social and individual choices, and are highlighting areas of uncertainty in the coming decades. The GEO-4 storylines differ along two axes: Global vs. Regional, Economic vs. Environmental emphasis. Thus, this distinction makes it easy to relate the GEO-4 narratives to the SRES narratives, as presented in Figure 7.3. ThEGEO-4 resulting scenarios are: "Markets First", "Policy First", "Security First", "Sustainability First". Figure 7.4 summarises the assumptions underpinning and distinguishing each scenario, while their dominant characteristics are described below (UNEP, 2007):

- **Markets First**: the private sector, with active government support, pursues maximum economic growth as the best path to improve the environment and human well-being for all. A key question it poses is: how risky is it to put the markets first?
- **Policy First**: the government sector, with active private- and civic-sector support, implements strong policies intended to improve the environment and human well-being, while still emphasizing economic development. A key question it poses is: will the slow and incremental nature of this approach be adequate?
- **Security First**: the government sector and the private sector vie for control in efforts to improve, or at least maintain, human well-being for mainly the rich and powerful in society. A key question it poses is: what might be the broader implications of security first?
- **Sustainability First**: the civic, government and private sectors work collaboratively to improve the environment and human well-being for all, with a strong emphasis on equity. A key question it poses is: what only some of the key actors actually follow through on the pledges made to address environmental and social concerns?

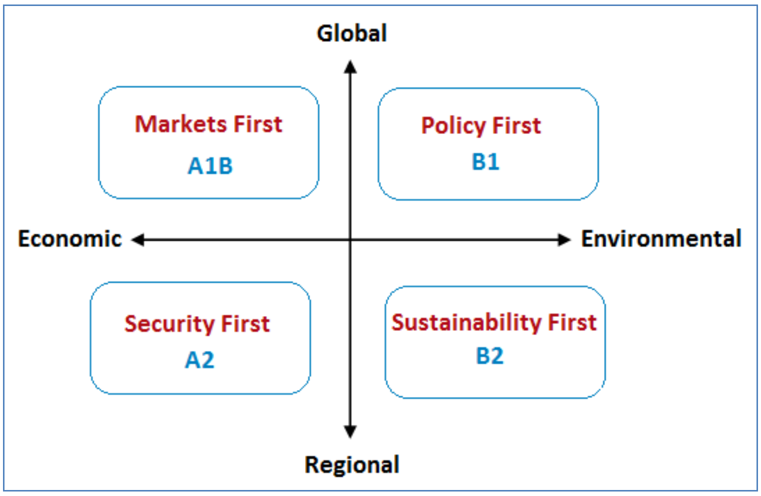

Figure 7.3: Linking narratives from GEO-4 and IPCC

Source: Fruhmann and Jager (2010)

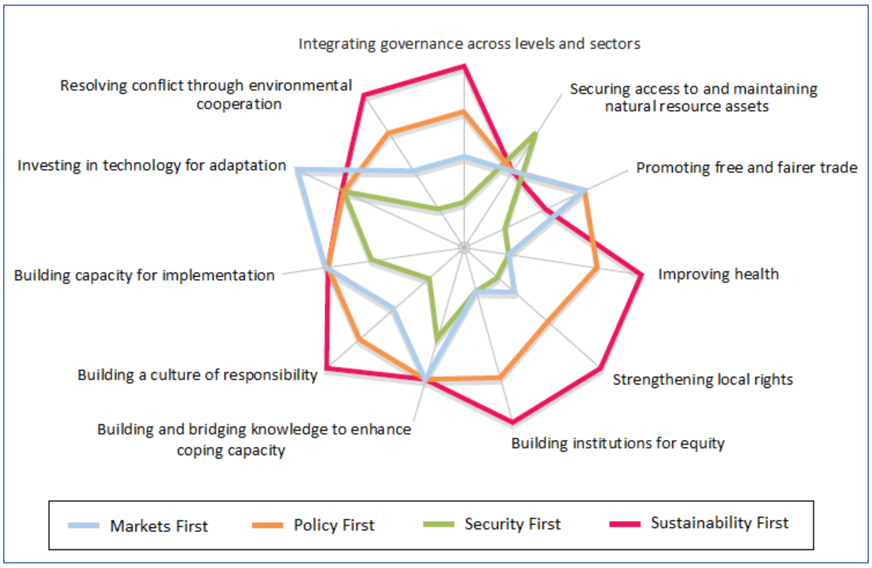

Figure 7.4: Strength of investments in opportunities to reduce vulnerability in human-environment systems across the GEO-4 scenarios

Source: UNEP, 2007

In the framework of the EU project SCENES (Water Scenarios for Europe and for Neighboring States) (Kok et al., 2011a), four narratives of European focus[3] have been developed for a time horizon up to 2050 based of the GEO04 scenarios. The purpose of the SCENES was to refine the GEO-4 scenarios and make them more specialized in the EU context and more explicit for each sector, focusing on the water sector (quality of, availability of, and demand for freshwater resources). The SCENES scenarios are" Economy First", "Fortress Europe", "Policy Rules", Sustainability eventually". Their positioning in comparison to the GEO-4 framework is depicted in Figure 7.5.

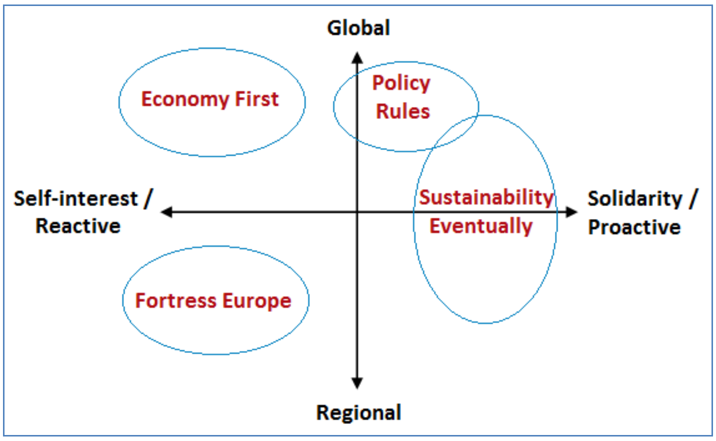

Figure 7.5: Positioning of the SCENES scenarios

[3] The regions of North Africa AND Middle East are also included

Source: Kok et al., 2011b

The methodology for the SCENES scenarios' development is based on the SAS (Story And Simulation) approach, linking storyline revision and modelling work in an iterative process. The qualitative scenarios are based on stakeholder participation in panels and describe a set of plausible futures up to 2050. The quantitative scenarios, produced by state-of-the art models, such as the WaterGap, complement the storylines by providing numerical information. In few words the scenarios can be described as follows (CESR, 2010):

- **Economy First (EcF)**: A globalised and liberalised economy pushes the use of all available energy sources and an intensification of agriculture where profitable. The adoption of new technologies and water-saving consciousness are low. Thus water use increases. Only water ecosystems providing ecological goods and services for economies are preserved and improved. Curtailed infrastructure, poor treatment and intensified agriculture lead to increased pollution. Poisoning incidents catch the interest of media and public. This and social tensions lead to upheaval in the 2040s. This triggers new cooperation to restore economic prosperity and make ground for social coherence.
- **Fortress Europe (FoE)**: A high number of crises (energy, financial, and climatic) result in an increasing instability and terrorist activities throughout the world, as well as in Europe. Subsequently, Europe closes its borders and concentrates on a series of security issues, including a central goal on self-sufficiency. Cooperation is difficult and alliances change, but perceived threats keep the EU together. The WFD becomes the Water Security Framework Directive with much less public participation, to tackle the increase and intensification of water conflicts. Water policies focus on water demand, which is largely satisfied by 2050.
- **Policy Rules (PoR)**: A stronger coordination of policies at EU level, but policies become slowly more ineffective. As a result, ecosystem services begin to deteriorate very significantly. Until 2030, EC becomes increasingly disappointed in the level of WFD compliance; issues of water quality and quantity are generally ignored; while there are emerging and increasing pressures on water resources. After 2030, climate change hits hard and changes public apathy, leading to WFD compliance that is higher than ever. By 2030, public participation increases, leading to local government support. By 2050, Europe is at the forefront of a new socio-economic paradigm of public/private partnerships and leads a global shift in this direction.

- **Sustainability Eventually (SuE)**: This scenario sketches the transition from a globalising, market-oriented Europe to environmental sustainability, where local initiatives are leading and where the landscape becomes the basic unit. This fundamental change in human behaviour, governance structures, and level of decision making, is projected to come about through a phase of strong top-down policies ("quick change measures"), accompanied with a set of "slow-change" measures that bear fruit in the long run.

The global or regional scenarios (e.g. GEO-4, SCENES) address global changes, and may not be able to fully capture the specific local characteristics. Thus, the specific scenarios need to be cross-validated with local conditions based on an analysis of the local drivers and input (expert knowledge) from local stakeholders, to assess their feasibility and validity (do they reflect plausible future stories?). Starting with the global perspective of the global/regional narratives their implications at local level (with an emphasis on the significant hot spots) must be examined by a set of indicators (drivers). These can be developed through a participatory process with stakeholders and sector experts. A tool that is available to assist in this is the "International Futures (IFs) software (Gordon et al., 2011). The IFs software was developed at Frederick S. Pardee Center for International Futures, School of International Studies, Josef Korbel of University of Denver (http://pardee.du.edu/access-ifs). IFs v7.15 (released in 2014) is available online (http://www.ifs.du.edu/ifs/frm_MainMenu.aspx) or for download. Implementations of all GEO-4 scenarios in IFs generally reflect the core assumptions of the scenarios, although they may differ somewhat from the GEO-4 descriptions, because of the structural and empirical specifications of IFs (including the limitations of the IFs system with respect to the representation of socio-political events). The IFs model consists of 11 main sub-modules (Figure 7.6), with basic connections among them: agriculture, economy, education, energy, environment, socio-political, health, infrastructure, international politics, population, and human development. Using the model's interface the user can drill down through categories and subcategories within each module to individual variables and parameters (Table 7.4), follow connections from one variable or category to another, or even search for specific variables and connections. As such, although the GEO-4 are already simulated in IFs and available to the user as default, the opportunity of customization is available, and with a variety of options: the user can select to add/remove components and variables as fit, to create a scenarios that are more tailored to the local specificities of the area under investigation, which is considered a strong added-value of the model.

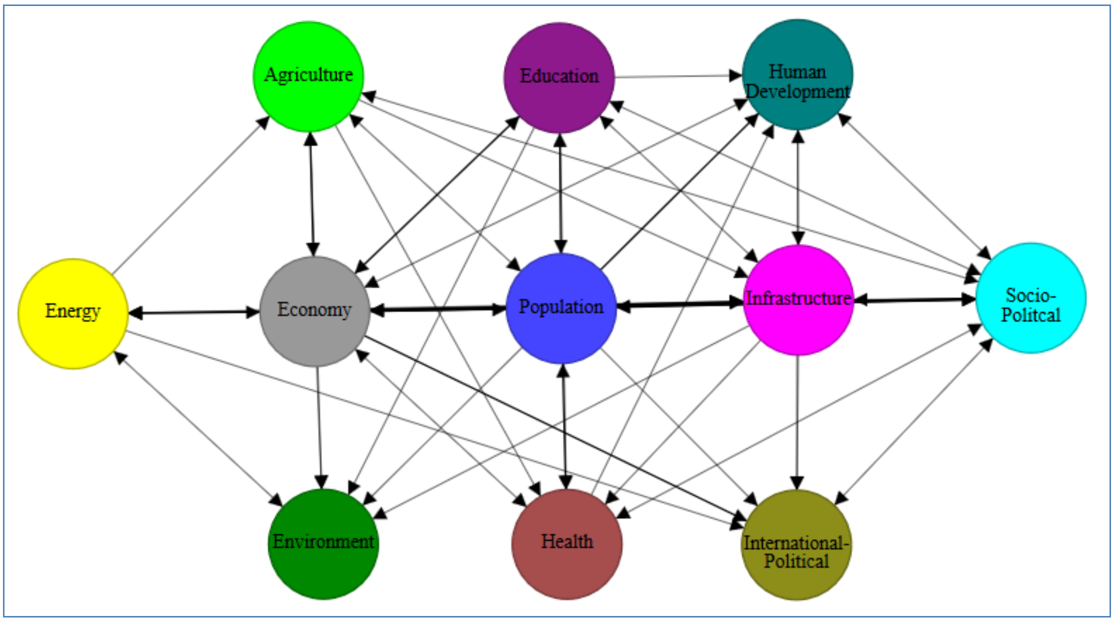

Figure 7.6: The network diagramme of IFs with the main sub-modules

Source: IFs website (http://54.69.84.211:8080/ifn/)

Table 7.4: List of main indicators used in the simulations of the IFs software

Variable Name per sub-module			
AGRICULTURE	**ENERGY**	**ENVIRONMENT**	**SOCIAL**
Crop - Agricultural demand	Energy imports	Annual carbon emissions from fossil fuels	Calories per capita available -
Crop - Agricultural imports	Oil - Energy production	Forest - Land	Literacy, percentage of population, 15 and older
Crop - Agricultural production	Energy price	Water usage	Total - Materialism/ postmaterialism index
Crop - Agricultural exports	Energy demand ratio to GDP -		Physical quality of life index
Yield in agriculture	Energy exports		Total - Survival/self-expression index
ECONOMIC	**POPULATION**	**POLITICAL, DOMESTIC**	**POLITICAL, INTERNATIONAL**
Private consumption	Birth	Freedom House freedom indicator	Aid (foreign)
Gross domestic product	Crude birthrate	Government balance	Power index
Gross domestic product	Deaths	Unskilled - Household dividends and interest	
GDP per capita	Infant mortality rate	Unskilled - Household social security payments	
GDP annual growth rate	Total Life expectancy	Unskilled - Household savings	
Globalization level index	Malnourished children as percent	Tax rate of central government	

Government consumption	Population		
Government expenditures	Population growth rate		
iMports	Population in urban areas		
eXports	Population in urban areas, growth rate		

Source: http://www.ifs.du.edu/ifs/frm_Report.aspx?Country=GR

7.3 Designing, integration and implementation phases

In order for DRM options to attain sustainable results they must be translated into concrete sectoral and policy targets, based on the robustness analysis, and then integrated in development frameworks and implemented by the relevant bodies. This process includes three phases: (a) the definition of policy targets (designing phase), (b) their internalization into national, sectoral, or local development agendas and plans (integration phase), and (c) implementation by the relevant governmental bodies (implementation phase).

7.3.1 Designing phase: Definition of policy targets

A target is defined as an objective metric of a policy goal. It is the value of a variable that policy-makers regard as ideal and use as the basis for setting policy actions. A target must be specific, measurable and time-bounded, and directly contribute to the achievement of the goal. To measure the progress made towards a target, indicators are most commonly used. The definition, nature and scope of a goal vs. a target vs. and indicator are presented in Table 7.5.

Table 7.5: Definitions and main attributes of a policy goal, target and indicator

	Definition (Suter, 2014)	Nature	Scope	Time frame
Goal	An ambitious commitment to reduce drought vulnerability and risk, and enhance the resilience and well-being on the drought affected communities and systems on a long-term basis. It is linked to the "aspiration"	Qualitative or Quantitative (e.g. reduce risk by x%, reduce environmental impacts)	National, sub-national	Medium to long-term
Target	A specific, measurable and time-bound outcome (result) that directly contributes to achievement of a goal. Ii is linked to the "action"	Quantitative (% reduction in unmet demand per sector, % increase in demand coverage and water supply reliability)	National, sub-national, local. May also be aggregated to assess national progress	Short to medium-term (could be updated based on progress and feasibility evaluation)
Indicator	A metric used to measure progress towards a target; generally based on available or established data compered against the baseline situation. It is linked to the "accountability" of the results	Quantitative (e.g. number of regional plans that internalized DRM targets, number of educational and awareness campaigns on water efficiency options, number	National, sub-national, local. May also be aggregated to assess national progress	Short-term (reproduced regularly)

	of households that implemented water saving fixtures, number of hectares that converted to drip irrigation, etc.	

The first step is to define the goals of the target setting process must be defined, e.g. the process must be credible, transparent, all-inclusive and participatory, accountable, based on best science and policy interfacing, and time-bounded. To define policy targets that are meaningful, attainable and acceptable it is of paramount importance to involve all stakeholders in the process, and implement a participatory approach. This can further create a sense of ownership, facilitating thus their implementation. The feeling of ownership and the understanding of the targets' rationale by the different stakeholders is important to the top-down commitment required during the internalization and implementation phases (Lester and Neuhoff, 2009). The second step of the process is to define the key questions to be addressed:

- What is the optimal number of targets for development agendas?
- How can we prioritize between potential targets?
- How can targets, it defined at national level, be differentiated between areas under different prevailing conditions?
- How can we account for inter-linkages across targets, thus ensuring an integrating approach that can maximize benefits?

The third step of the process involves the definition of criteria for selecting and prioritizing well-defined targets. An indicative list of such criteria includes:

- **Policy relevance**: the target has a clear and intuitive relation to the goal(s) that is expected to contribute to.
- **Clarity**: the target must be well-defined, rational, transparent and easy to communicate
- **Robustness**: the target has to be robust when assessed against alternative scenarios. Some targets (i.e. selected solutions of the optimization) may be found to be more robust under changing climatic and/or socio-economic conditions while others may be more sensitive. A robustness analysis is thus when prioritizing targets.
- **Attainability**: the target is realistic and achievable within the time allotted, and the required resources (human and financial) are viable.
- **Ambition**: the target, while realistic, must trigger improvements that would not otherwise be achieved.

- **Scalability**: the target (if national or sub-national) can be tailored to local circumstances.
- **Quantification**: the target can be quantitatively quantified; it represents a specific value (numeric, rate of change or absolute).
- **Measurability and Ratability**: the sources of information and data can be collected to assess progress, taking into account varying technical capacities. The target comparable to a baseline: the starting point is known and defined, while progress towards the target can be measured and rated on the basis of indicators, informing thus policy response.
- **Disaggregation and sub-assessment potential**: information on the target can be assessed by sub-groups to assess if progress is shared evenly or if it is bounded by some specific constraints (e.g. cultural, educational, etc.), contributing thus to a re-designing process.
- **Multi-purpose and mutli-dimensionality**: the target clearly links to the three dimensions of sustainable development (economic, social, environmental), and can potentially support achievement of more than one goal.
- **Compliance and complementarity**: it is consistent with existing legislative frameworks and agreements, while it can complement (yet not overlap with) other targets. It has thus implementability and integration potential without requiring major institutional changes and transformations
- **Global Cost-effectiveness**: transaction or other hidden cost do not outweigh the benefits of target

7.3.2 Internalization and implementation of policy targets

The policy integration phase consists of defining possible entry points, initiating instruments and mechanisms to internalize the targets, draft suggestions how to implement DRM in action plans, development programmes, etc., identifying the necessary preconditions and enabling factors. The following elements must be considered:

- Time frame to achieve the target
- Placement of the target at the appropriate level (national, subnational, regional), i.e. identification of relevant and suitable entry points
- Definition of the nature of the target (binding, non-binding) and the enforcement method (voluntary, legal requirement, etc.)

The implementation of the target must be defined against a specific **time-frame**, while adequate resources need to be committed and secured. Time frames vary depending on each case. Targets defined on a longer time-frame provide less structure for actual implementation since it is difficult to break them down into smaller implementation steps (e.g. emission reduction targets). Shorter time-frames on the other hand allow for flexibility in the design of target regimes, yet they may not allow enough time for the full potential of the policy impact to develop (Lester and Neuhoff, 2009). A dual framework, using a medium to long-term time frame while also defining short-term milestones (e.g. biannual) may, in the case of DRM, deliver optimal results, since it can provide policy stability for continuous national government action on one hand, while incentivizing regular actions to achieve the intermediate milestones.

The placement of the target at the appropriate level requires the commitment of the stakeholders to embed them as essential components of their development agendas, rather than implementing some of the options as add-on or one-off interventions (UNDP, 2011). Each DRM target (and the measures that are needed to achieve this target) must permeate the relevant types and levels of planning and decision-making frameworks. The placement of the target at the appropriate level (national, subnational, regional, local), is paramount to its successful implementation. For example, long-term measures designed to remove underlying vulnerabilities would be mainstreamed in the concerned sectoral policies or within broad-based national development planning frameworks (e.g. National Development Plans – NDPs, Structural Funds Programmes, etc.), while short and mid-term measures may be integrated in existing programmes and projects at national or sub-national level (e.g. community-based natural resource management initiatives) (UNDP, 2011). Targets can be defined at multiple levels, e.g. at a national level and downscaled in a regional or local context, or at the local level and up-scaled to national when they have been validated for their good performance. It is important thus, to identify relevant and suitable "entry points" and "key actors". By entry points we mean planning and developing frameworks that can accommodate the targets (Table 7.6), while key actors are individuals and/or entities responsible for decision-making and funding allocation with a significant level of influence. The identification of the entry points is important, but it needs to be complemented with an in-depth knowledge of the key phases and steps that are undertaken leading to the development and/or updating of these framework and plans, such as: the stages of and timing of taskforce and working groups' formation, agenda setting, internal discussion, negotiation phase, public consultation, etc. This knowledge can ensure that action is taken at the right time. The specificities of the internalization procedure vary depending on the DRM targets and options that ate to be mainstreamed and the particularities of the entry points. For example Integrating targets into existing Drought Contingency Plans may be straight forwards, while mainstreaming into sectoral strategic plans may pre-require changes in policy orientation and the process may be more time and effort consuming (UNDP, 2011). International incentive schemes (as entry points) could be linked to the targets to secure external funding sources and/or attract investments. Yet, this could create a double-conditionality (Lester and Neuhoff, 2009). Countries may opt for specific actions that are linked to international support (it raises an issue of subjectivity), and international support is only provided if the action is successfully implemented on the basis of international standards and metrics.

Table 7.6: Indicative list of framework and plans that can be used as entry points at different levels

Level	Possible entry point of the target
National	National Development Plans Structural Funds' Planning Porgrammes Sectoral Strategies and Programmes Sectoral Policies (water, land use and allocation, energy) Environmental and/or Water Laws, Regulations and by-laws Resource efficiency management plans National Action Porgrammes for International Conventions (e.g. UNCCD[4], UNFCCC[5], DRPC[6])
Regional	Regional actions plans Regional development frameworks District plans Sectoral projects Farming investment plans
Local	Community conservation projects Irrigation projects Local development frameworks Contingency plans Environmental farm planning

The definition of the nature of the target and the applicable enforcement method are crucial with regard to its acceptability and implementability. A target can be binding, non-binding, or conditional and constitute a pre-requisite for some actions (e.g.

[4] UNCCD: United Nations Convention to Combat Desertification

[5] UNFCC: United Nations Framework Convention on Climate Change

[6] DRPC: Danube River Protection Convention

obtaining national funding for developing alternative water supplies such as desalination units is conditioned to the fact that irrigation efficiency had reached a target level above 90%). An adequate enforcement method must also be in place in order to secure implementation. This method can be a voluntary agreement, a legal requirement, an imposed obligation (paternalism), or based on public accountability, reward schemas and financial incentives. It is also important that pre-conditions for effective implementation of the target and associated measures exist. These may include the availability of adequate human and financial resources, a robust institutional setting, a dedicated plan for sharing of roles among stakeholders' and enforcement bodies, etc. The absence of the "right" pre-conditions questions the actual implementability or suitability of the proposed measures. Good governance schemas must be identified and mobilized, while capacity building activities are necessary prior and during the implementation phase. Good governance has eight major characteristics: it is participatory, consensus-oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive (UNDP, 2008). Capacity building among the stakeholders, transparent communication, and public awareness raising of the different target and end-user groups (e.g. farmers, household owners, etc.) can facilitate overcoming institutional, social and cultural bottlenecks.

7.4 Evaluation phase: Monitoring the impacts of DRM mainstreaming

Policy evaluation, in general, uses a range of research methods to systematically investigate the effectiveness of policy interventions, implementation and processes, and to determine their merit, worth, or value in terms of improving the social and economic conditions of different stakeholders (Her Majesty's Treasury, 2011). Monitoring of the impacts of DRM mainstreaming is essential as it allows the evaluation of the policy effectiveness and feeds back to the re-definition and re-design of targets (if deemed necessary) (Figure 7.7). Monitoring and evaluation should be conducted on a regular basis to allow for early identification of problems or malfunctions. The impact evaluation of DRM mainstreaming seeks to answer the fundamental question "Did DRM mainstreaming produced the intended outcomes and impacts?" Thus, this impact evaluation is set to examine changes in key indicators that have occurred since the implementation of DRM options, and the extent to which changes can be attributed to the mainstreaming process.

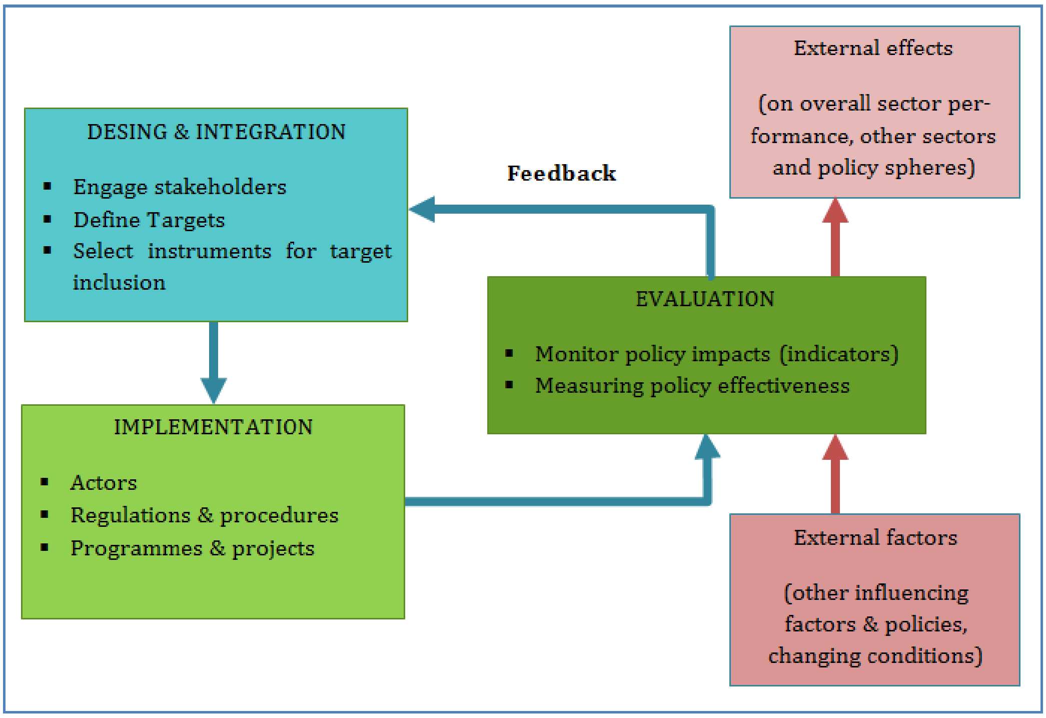

Figure 7.7: The feedback loop between policy evaluation, design-integration and implementation

Source: adopted from Metz, 2005.

DRM mainstreaming impact evaluation can have multiple purposes and goals, including:

- **Relevance**: Were the DRM mainstreaming targets well-conceived? Does it remain relevant to the problem it was intended to address?
- **Efficiency**: Did DRM mainstreaming delivered its targets in a timely and cost-effective manner? Can the changes in outcomes be attributed to the DRM mainstreaming?
- **Effectiveness**: Have the expected results been achieved? What has affected achievement of the results? What is the relative cost-benefit or cost-effectiveness of the entire mainstreaming process? What was the economic impact of the policy?
- **Impact**: What is the impact of mainstreaming, by measuring changes in short-term, intermediate and long-term outputs, outcomes and impacts? To what extent has DRM mainstreaming contributed to reduction of vulnerability? Are there unanticipated positive or negative consequences? Did contextual factors influence the level of impact?
- **Sustainability**: Is there an enabling environment that can further support the ongoing positive impacts? Can the outcomes and be sustained beyond current funding?
- **External utility**: To what extent is the DRM mainstreaming in another situation?

The focus of the evaluation may be on the outputs, the outcomes or the impacts on the mainstreaming, on the costs of implementing the targets, or on the monetary savings resulting for the implementation of the policy measures. It is relevant to identify specific evaluation questions that will guide the selection of the appropriate evaluation method and indicators[7]. Such questions can be: What was the change in the outputs, outcomes and impacts of interest? Did the policy specifically contributed to these changes and how? Were there any externalities? Did the policy have any unintended or adverse consequences? The selected indicators must be able to measure progress towards the stated targets, and their results should be reported to stakeholders and the public. There are four main categories of performance indicators, focusing on input, output, outcome and impact. These categories, along with some examples for targets in the agricultural and domestic sectors are presented in Figure 7.8. Outcome-based indicators can be considered as intermediate, linking activities (output) with impacts and could thus facilitate in the identification of causal relations. Although impact indicators reflect best

[7] Indicators are specific, observable, measurable characteristics of changes that demonstrate progress toward outcome or impact.

whether the target has been achieved, they may not be feasible to calculate on the short-term since impacts are often observed on a longer run. It this thus advised to combine them with output and outcome indicators, so that the progress of the implementation can be monitored and evaluated. Indicators can also be combined across targets (e.g. in case of sectoral target) to capture cross-cutting progress and combined effects. Finally, the evaluation process needs to consider the factors that can facilitate or hinder the monitoring and evaluation process, and identify solutions (Table 7.7).

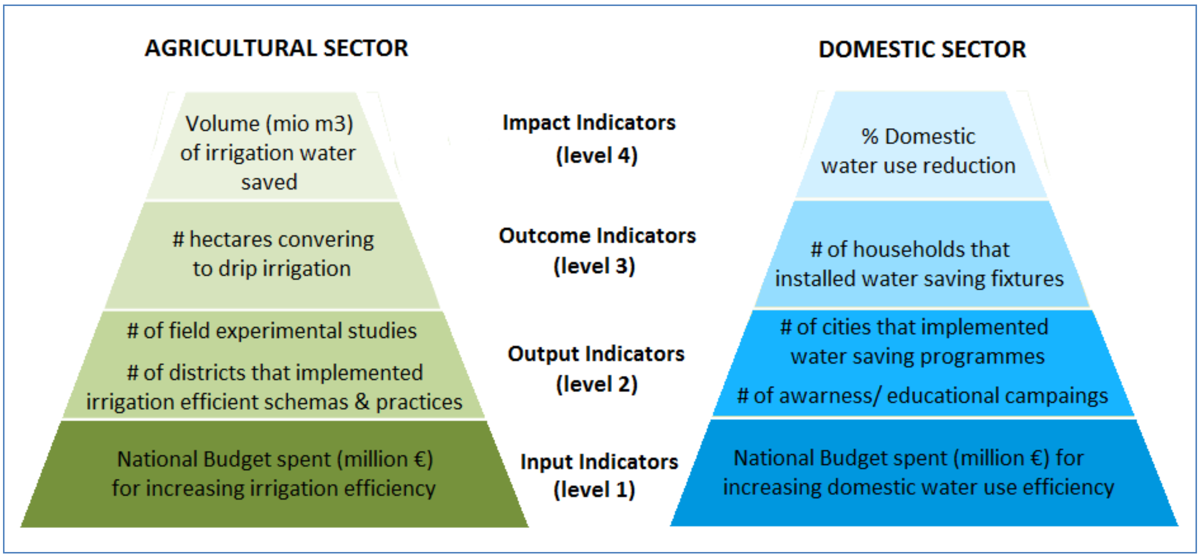

Figure 7.8: Performance indicators to evaluate policy targets in the agricultural and domestic sectors

Table 7.7: Potential DRM mainstreaming evaluation challenges and suggested solutions

Challenges	Suggested Solutions
Externalities and contextual factors	Measure contextual factors (as far as possible), and define the nature and extent that they have an influence on the impacts Use control and comparison groups
Length of time required to observe long-term impacts	Measure additional short-term indicators (outputs, outcomes) that have clear causal relations to the longer-term impacts
Lack of access to appropriate data	Identify alternative datasets (e.g. satellite land use or soil moisture images), create online impact reporter tools for direct data entry by the beneficiaries
Lack of human resource to collect and evaluate the indicators	Set up an impact monitoring unit from the beginning of the process and secure adequate funding
Week relation between targets and impacts	Need to revisit and re-assess the targets and/or the selected performance indicators and redesign if necessary

Source: adopted from NCIPC, 2015.

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CHAPTER 8 – Pilot Testing in the Ali-Efenti Basin

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8 PILOT TESTING IN THE ALI-EFENTI BASIN

8.1 Overview of the Ali-Efenti case study

The methodology presented in Chapter 3, and detailed in the following Chapters 4-7 has been tested in the Ali-Efenti basin for validation purposes. The following steps have been implemented:

1. Analysis and mapping of the drought hazard risk in the basin, using the Drought Hazard Indicator (DHI) (as described in Chapter 4), calculated for the period 1981-2010 in 17 rain gauges within the basin and spatially interpolated across these stations. The DHI has also been calculated for the sub-periods 1981-1995 and 1995-2010 to allow for the understanding of the drought hazard evolution.
2. Assessment of the components and main drivers of vulnerability in the Ali-Efenti basin. For this purpose a Distributed (node-based architecture) Water Resources Management Model (WRMM) has been developed for the Ali-Efenti catchment, using the WEAP21 platform. The model simulates all the features of the hydrological cycle and water uses per sector and demand node, for the baseline period 1980-2010.
3. Calculation of drought vulnerability indicators using output parameters of the WRMM, namely the unmet demand, which are then blended into a Drought Vulnerability Index (DVI) (as described in Chapter 4). The DVI is derived and mapped at the sub-catchment level (for 17 sub-catchments within the basin), for all three reference periods (1981-2010, 1981-1995, 1996-2010).
4. Development of a Drought Risk Profile (DRP) for the Ali-Efenti basin, on the basis of the Drought Risk Index (DRI) (as described in Chapter 4) by multiplying the DHI and DVI. A relevant classification of the drought risk across the basin area is performed to visualize the regions of low vs. high risk, and a comparison is performed across the reference periods.
5. Selection of a bundle of demand management interventions for the urban and agricultural sectors on the basis of the analysis of the DRP of the previous step. Development of “intervention curves” for the selected options (as described in Chapter 5) and simulation of the measures in the WEAP21 WRMM. For these purpose user-defined variables have been coded in WEAP21.

6. Application of an optimization process to select the optimum mix of measures across the two sectors (i.e. urban and agriculture) (as described in Chapter 6). For this purpose a bi-spoke code has been developed in MATLAB to allow for the interaction between WEAP and MATLAB, and the MATLAB optimization suite has been used.
7. Testing of the robustness of the optimal measures (i.e. selected solutions of the optimization Pareto front) against future climate and socio-economic scenarios. For that purpose three future scenarios have been developed (up to the target year 2030) and simulated within the WEAP21 WRMM to allow for an accurate representation of the future conditions and their impacts on the water resources availability and demand in the basin.
8. Definition of relevant policy targets on the basis of the robustness check performed in the previous step, in order to allow for the mainstreaming of drought risk management into development frameworks.

The details and results of each of the above steps are presented and discussed in the following sections of this Chapter. A schematic flowchart of the application on the Ali-Efenti is illustrated in Figure 8.1.

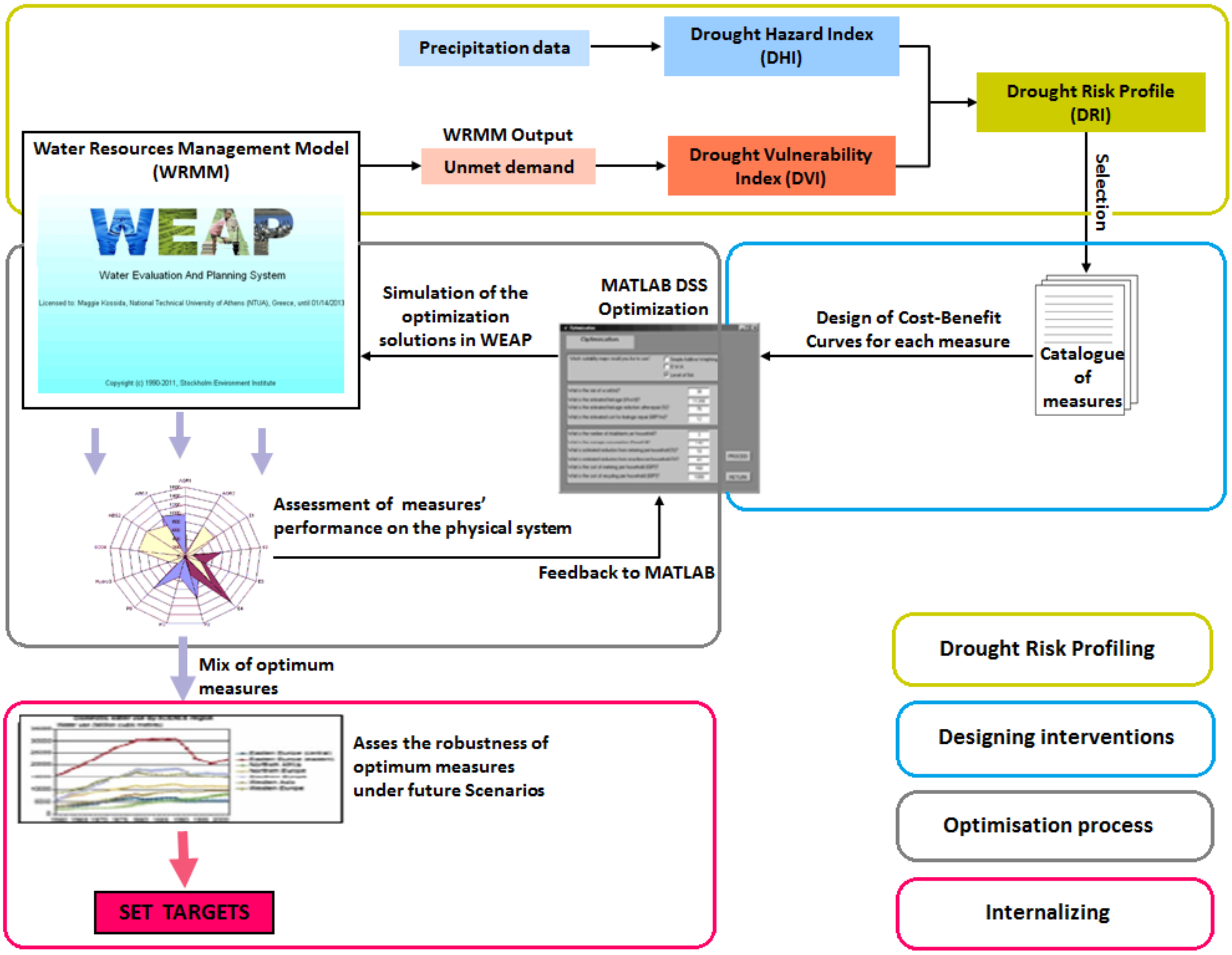


Figure 8.1: Schematic flow chart of the Ali-Efenti case study

8.2 Description of the pilot test area

- Physical and Economic characterization

The pilot test area is the Ali-Efenti catchment (Figure 8.2), located in the Northwestern part of the Pinios River, in Thessalia River Basin District (GR08), in Central-Eastern Greece. Thessalia is the most productive agricultural region of Greece. Pinios River and its tributaries traverse the plain, draining in total about 9,500 km2. The main cultivated crops are cotton, wheat and maize, while grapes, olives and citrus fruits are also cultivated. The drainage area of Ali-Efenti is about 2,920 km2 (representing about one third of the Pinios River Basin), with a total permanent population of 190,276 inhabitants. The Ali-Efenti basin has extended irrigation areas (the main crop cultivated is cotton), while irrigation efficiency is low. Imbalance between demand and availability (water stress) is frequent, and the unmet demand is highly pronounced during the summer period. As a result over-abstraction has led to environmental impacts, such as the degradation of the groundwater resources and declining groundwater levels.

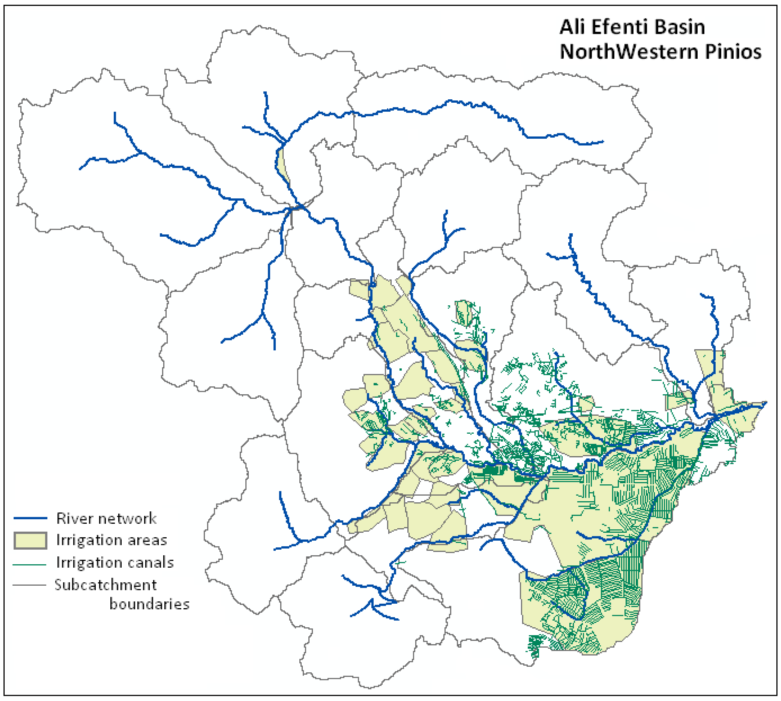


Figure 8.2: The Ali-Efenti basin in Pinios

In the Ali-Efenti basin there are 8 administrative units, namely the municipalities of Trikala, Pyli, Kalambaka, Farkadona, Mouzaki, Palama, Plastira, Kardita (as a whole or part of). Two main urban centers, the city of Trikala and the city of Karditsa are within the basin, while numerous significant peri-urban settlements are also present (e.g, Kalambaka, Mouzaki, Neoxori, etc.). The total permanent population of the area is 190,276 inhabitants, while the population of the main municipalities (with more than 5,000 inhabitants) is presented in Table 8.1 below.

Table 8.1: Permanent population per municipality, in the municipalities with more than 5,000 inhabitants

Main municipalities	Number of inhabitants
Trikala	57,914
Karditsa	40,478
Kalambaka	11,347
Mouzaki	9,187
Oixalias	5,457

In terms of land use the area is dominated by agriculture. The land use types are presented in Figure 8.3, while their respective coverage (in km^2 and as % of total area) is presented in Table 8.2. The area is dominated by agricultural land and forests (about 33% each), followed by pasture (31%) and urban areas (2%), while wetlands and water bodies only account for 1% of the total area. The share of cultivated crops (within the agricultural land use) are also presented in Table 8.3, where it is clearly demonstrated that cotton is dominating 10% of the total basin area corresponding to 44% share within the agricultural land use, followed by winter wheat, maize and alfalfa. With regard to other land use types, 11 industries (dairy products, oil products, meat products, structural materials, textiles) and 4 Wastewater Treatment Plants (WWTPs) are located within the catchment as presented in Figure 8.4 below. The long-term annual average precipitation is presented in Figure 8.5 where a spatial variability from higher values (up to 1,630 mm) in the west part to a lower precipitation (down to 460 mm) in the eastern part can be observed. Drought episodes are frequent in the area, and desertification is becoming an issue.

Table 8.2: Land use in the Ali-Efenti basin (based on Corine Land Cover – CLC2000)

Land Use Type	Area (km^2)	% coverage of the total basin area
Forest	955.60	32.72%
Pasture	895.10	30.65%
Agricultural land	679.30	23.26%
Agricultural land under fallow	293.76	10.06%
Wetlands and water bodies	28.46	0.97%
Urban areas	68.38	2.34%

Total	**2,920.59**	**100%**

Table 8.3: Main crops cultivated in the Ali-Efenti basin

Crop	Area (km²)	% of agricultural land occupied by the crop	% coverage of the total basin area
Cotton	297.85	43.85%	10.20%
Maize	126.41	18.61%	4.33%
Winter wheat	170.36	25.12%	5.84%
Alfalfa	66.95	9.86%	2.29%
Sugar beets	10.5	1.55%	0.36%
Olive trees	5.97	0.88%	0.20%
Orchard trees	1.00	0.15%	0.03%
Total	**679.30**	**100%**	**23.26%**

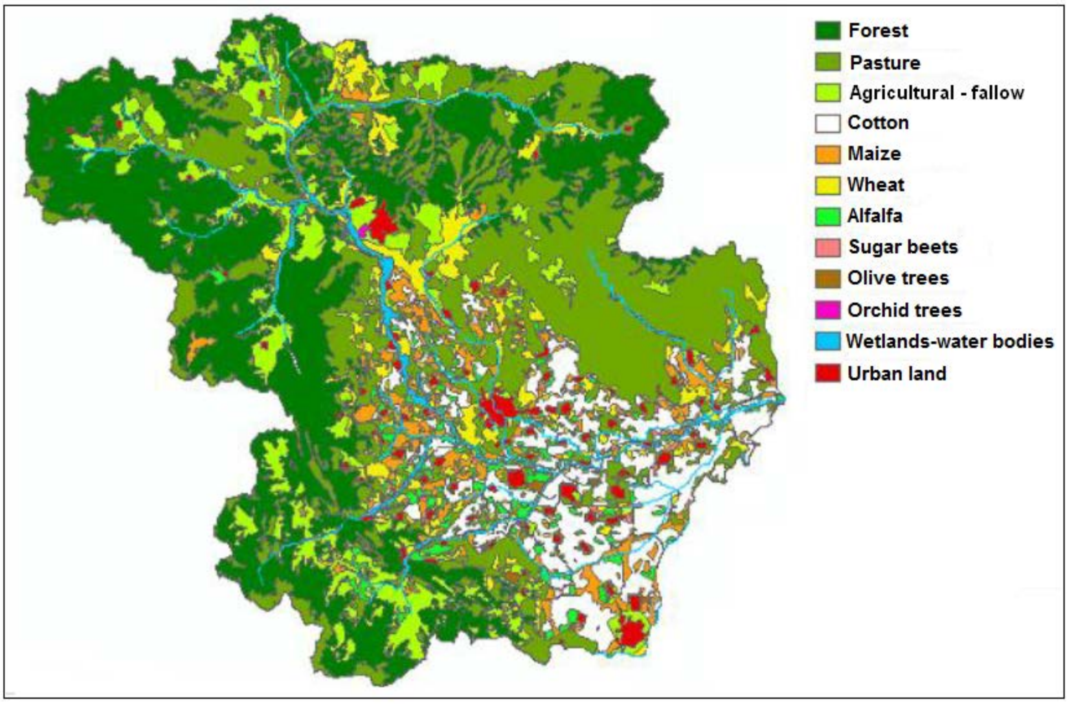


Figure 8.3: Land use in the Ali-Efenti basin.

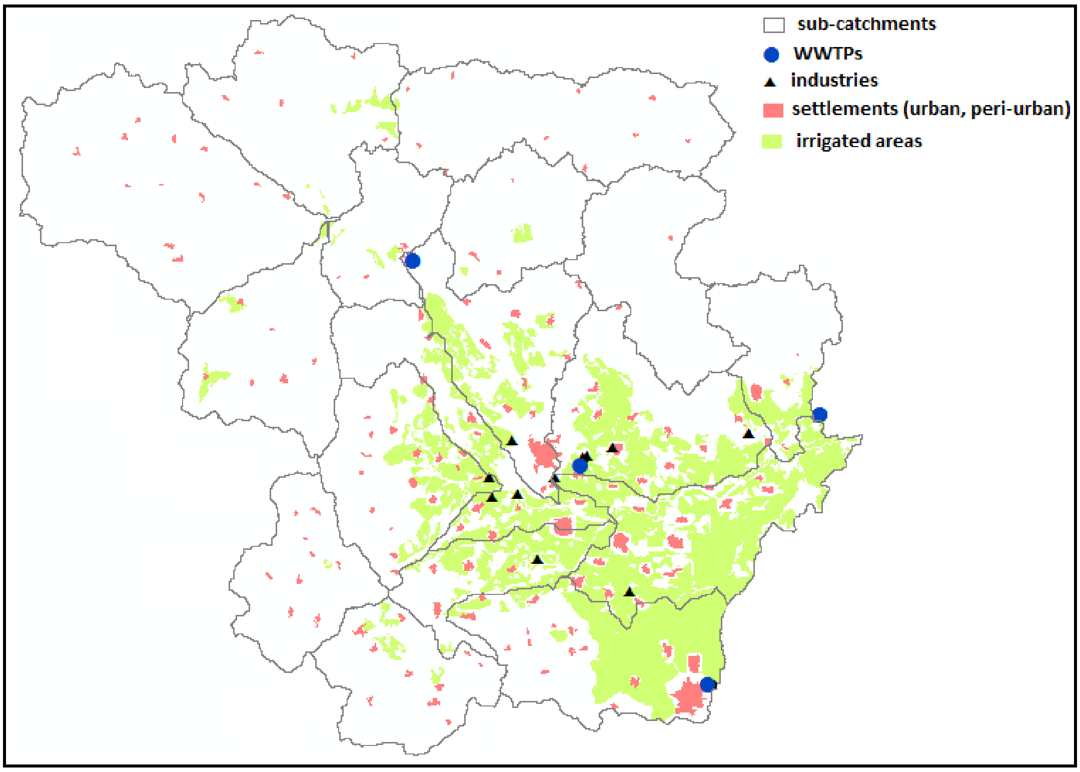


Figure 8.4: Location of industries, WWTPs, main settlements and irrigated areas within the Ali-Efenti catchment.

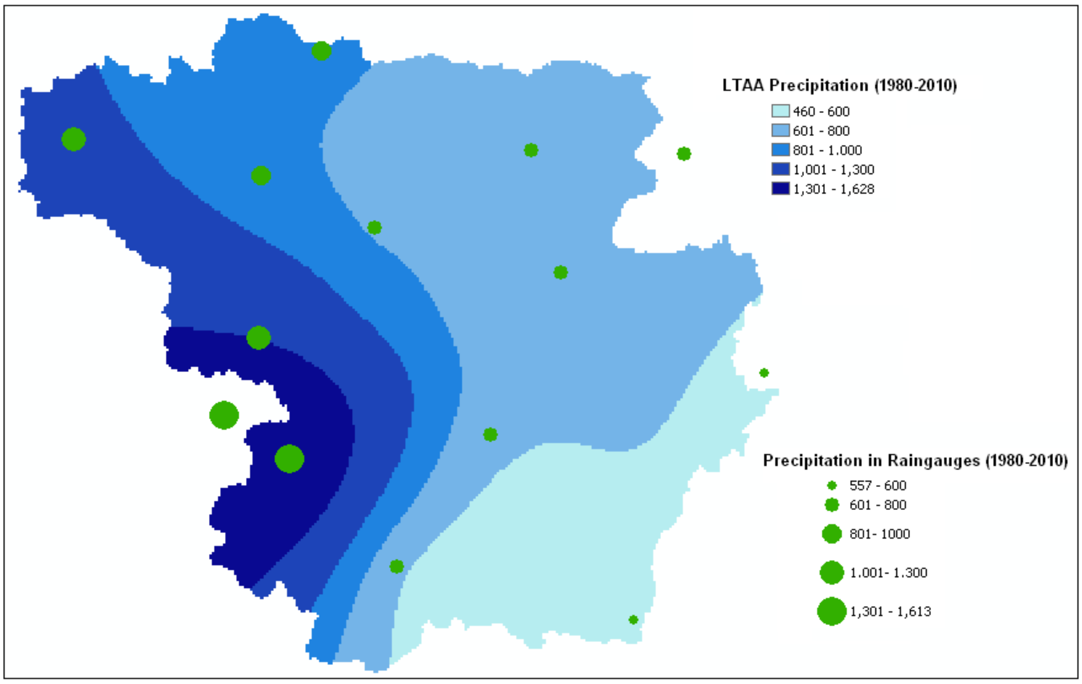


Figure 8.5: Long-term Annual Average (LTAA) Precipitation in the Ali-Efenti basin for the period 1980-2010.

- Institutional and policy setting

The water resources management in the entire Pinios River Basin has not been and sustainable so far. In the last decade a copiousness of Regulations, Decisions, Laws, Circulars, Common Ministerial Decisions, etc. have been edited concerning the implementation of agricultural, water allocation and environmental protection activities in the framework of the CAP, WFD and National Agricultural Policy. Yet, this legislative framework was not satisfactory implemented in the Pinios RB. Among the reasons for the non-satisfactory implementation of the legislative framework are the poor monitoring due to the inadequate and inappropriate staff and the high monitoring costs, the lack of public understanding of the environmental concerns and cause-effect relationships, the lack of incentives to comply with legislation (Petalas et al., 2005), and the poor enforcement and control (e.g. uncontrolled illegal abstractions, inadequate pricing system, etc.). The loose institutional setting and the weak cooperation among the responsible authorities has contributed to the inability of enforcement and control, subsequently leading to the realization of numerous illegal abstractions (Goumas, 2006) and the building-up of water conflicts among the users. An example can be illustrated by the pricing of irrigation water: in most cases of irrigation, the quantity of the consumed water is not measured, while the charge is based on the irrigated area regardless of the type of crop, season, and method of irrigation (i.e. pricing per hectare). This pricing policy provides minimal motivation for water conservation, in contrast to the volumetric methods, where pricing is based on the volume of water consumed or another correlated metrics (e.g. energy consumption for pumping). Moreover there is a different "pricing policy" for most of the Local Organizations of Land Reclamation - LOLR (which are for the management of water resources at the local level) and different billing methods, resulting in different water prices for irrigation water (Table 8.4). The current response and mitigation have focused on fragmented policy measures, including a number of projects aiming at the utilization of water resources (such as dam construction, water reserves, artificial lakes etc.), and at research activities on water management/irrigation practices. The allocated subsidies to farmers to replace traditional non-irrigated crops like wheat with irrigated crops like sugar beet, cotton, , etc., and to acquire individual irrigation equipment systems (such as high pressurized mobile rain gun systems and center pivot sprinkler systems) led to the increase of irrigation needs and to over-abstraction. At the same time, as the area is among the most productive agricultural region of Greece and with significant competing water uses, the socio-economic impacts of drought are a major challenge. Yet, operational Drought Management Plans (DMPs) or other policy instruments are lacking, and drought management is currently based on "crisis management" rather than on a pro-active and preparedness approach.

Table 8.4: Irrigation water prices across different prefectures.

Prefecture	Average price (€ /ha)
Larissa	289.80
Karditsa	197.80
Trikala	137.30

Source: Hellenic Ministry of Environment and Climate Change, 2008

8.3 Mapping and evolution of the drought hazard in the Ali-Efenti basin

In the current section, the proposed methodology for assessing drought hazard on the basis of the developed Drought Hazard Index (DHI) is tested. The results of the drought hazard analysis in the Ali-Efenti catchment are presented focusing on:

- the analysis of the drought occurrence and characteristics based on the SPI-12 and the four developed sub-indicators as discussed in the previous Chapter 4;
- the mapping of the drought hazard in the entire catchment area on the basis of the newly proposed indicator DHI, and the assessment of its spatio-temporal evolution and trends.

For the analysis of the drought hazard in the Ali-Efenti, monthly precipitation data have been used from 17 rain gauges homogeneously spread in the catchment, covering the 30-year period 1981-2010 (Figure 8.6). The analysis targeted the entire 30-year period, as well as the 15-year sub-periods 1981-1995 and 1996-2010 to allow for cross-comparison and conclusions on the evolution of the drought hazard.

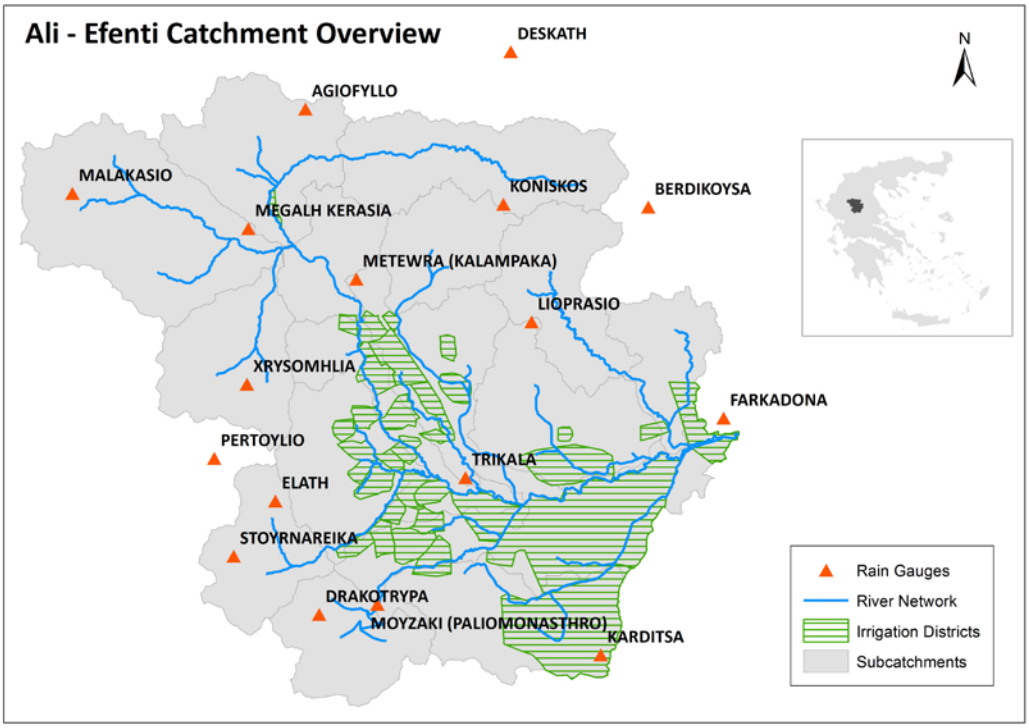


Figure 8.6: Overview of the distribution of rain gauges used in the drought hazard analysis of the Ali-Efenti catchment

The SPI-12 has been used as a basis for the analysis of drought occurrence in the Ali-Efenti catchment with a view of eliminating seasonal variability and capturing signals of distinct drought events associated with hydrological drought. SPI-12 has also been used in previous drought analysis for the Thessalia area for the period 1960-1990 and was found adequate to capture drought conditions (Loukas et al., 2007). Based on the SPI-12 timeseries, calculated in each of the 17 rain gauges in the area, the drought episodes of the 30-year period 1981-2010 have been identified. Figure 8.7 presents an overview of the drought events per station, along with their durations and magnitudes. We can observe commonalities across the stations in terms of drought occurrence, with the main drought events noticed during the years 1988-90, 1992-94, 2000-02 and 2007-08. The year 1988-90 has also been defined as a period of severe drought in Loukas et. al., 2007. The period 1988-94 could in fact be considered as a prolonged event, interrupted by the wet year 1990-91, which is consistent with the Loukas with Vasiliades, 2004). Some less significant events and of local character are additionally observed in some stations during 1983-85 and 2004-05. With regard to the main drought events, the respective magnitudes and durations range across the stations, from as low as 7 to as high as 58 for the magnitudes, and from 9 to 47 months duration. In some stations, we can observe that two or more episodes have been merged into a prolonged drought event of very high magnitude (DM) and duration (Agiofyllo: DM=92, duration 70 months within 1988-93; Deskati: DM=86, duration 75 months within 2004-10; Trikala: DM=66, duration 83 months within 2004-10). The overall statistics of the drought magnitudes and durations across all stations are presented in Table 8.5. Overall, it can be observed that the event with the largest drought magnitude across the observation gauges has been experienced within the period 1981-1995, while the event with the largest duration has been experienced within the period 1996-2010. With regard to the prolonged events, with durations of more than 60 months experienced in few locations, these are more apparent during the recent period 2004-2010.

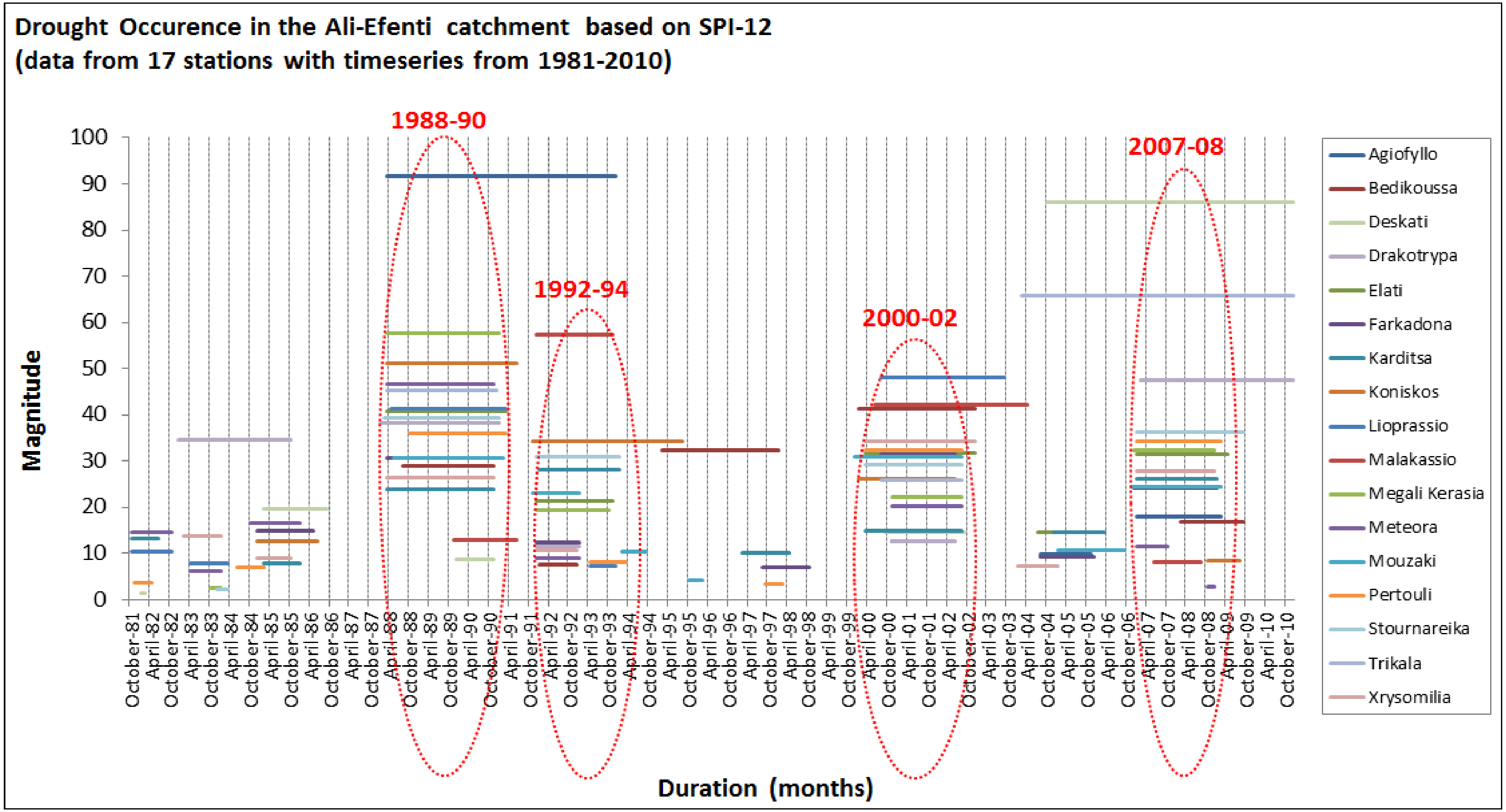


Figure 8.7: Drought occurrence in the Ali-Efenti catchment during the period 1981-2010 based on the SPI-12.

Note: The red circles denote the years with the main observed events.

Table 8.5: Characteristics of the main drought events in the Ali-Efenti

Statistics	Main Drought Events			
	1988-90	1992-94	2000-02	2007-08
Number (%) of stations where the event was observed	17 (100%)	15 (88%)	17 (100%)	16 (94%)
Average DM*	36.7	20.1	27.7	24.6
Max DM*	57.7	57.5	48.0	47.6
Average duration*	32	19	29	25
Max duration*	40	46	47	47

** The 3 prolonged drought events experienced in the 3 locations mentioned previously are excluded from these statistics.*

The above findings of the SPI-12 analysis are verified by the hydrological observations in the catchment. Although the available hydrological data do not consistently cover the whole study period, discharge data from the Kefalovrysso spring (located in center of the catchment) and the catchment outlet (Ali-Efenti streamflow station) also demonstrate low values during the periods of drought events as identified by the SPI-12 analysis (Figure 8.8).

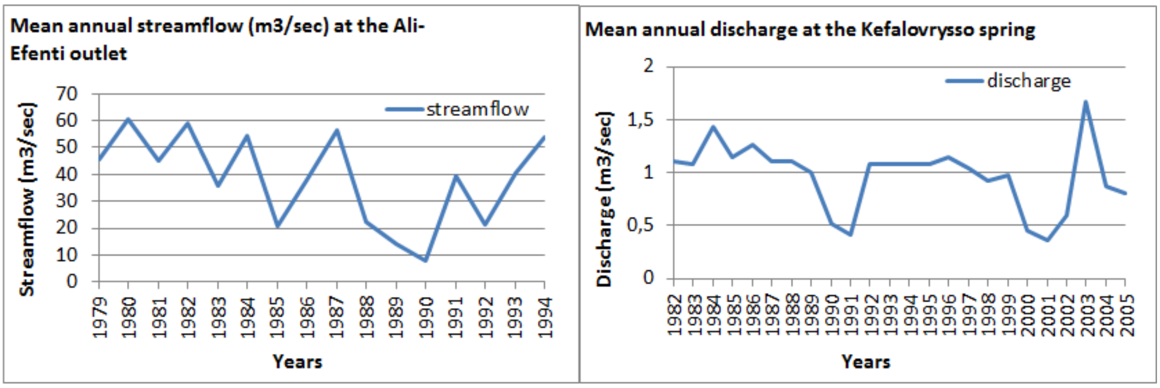


Figure 8.8: Mean annual discharge at the Ali-Efenti outlet (left) and at the Kefalovrysso spring (right).

By post-processing the results of the SPI-12, the four sub-indicators (FRQ, FRQ24, DMmax, dmax) have been estimated for each rain gauge station (as discussed in Chapter 4), for the entire 30-year period 1981-2010, as well as for the sub-periods 1981-1995 and 1996-2010. The values for each sub-indicator in each station (for the period 1981-2010) are presented in Figure 8.9.

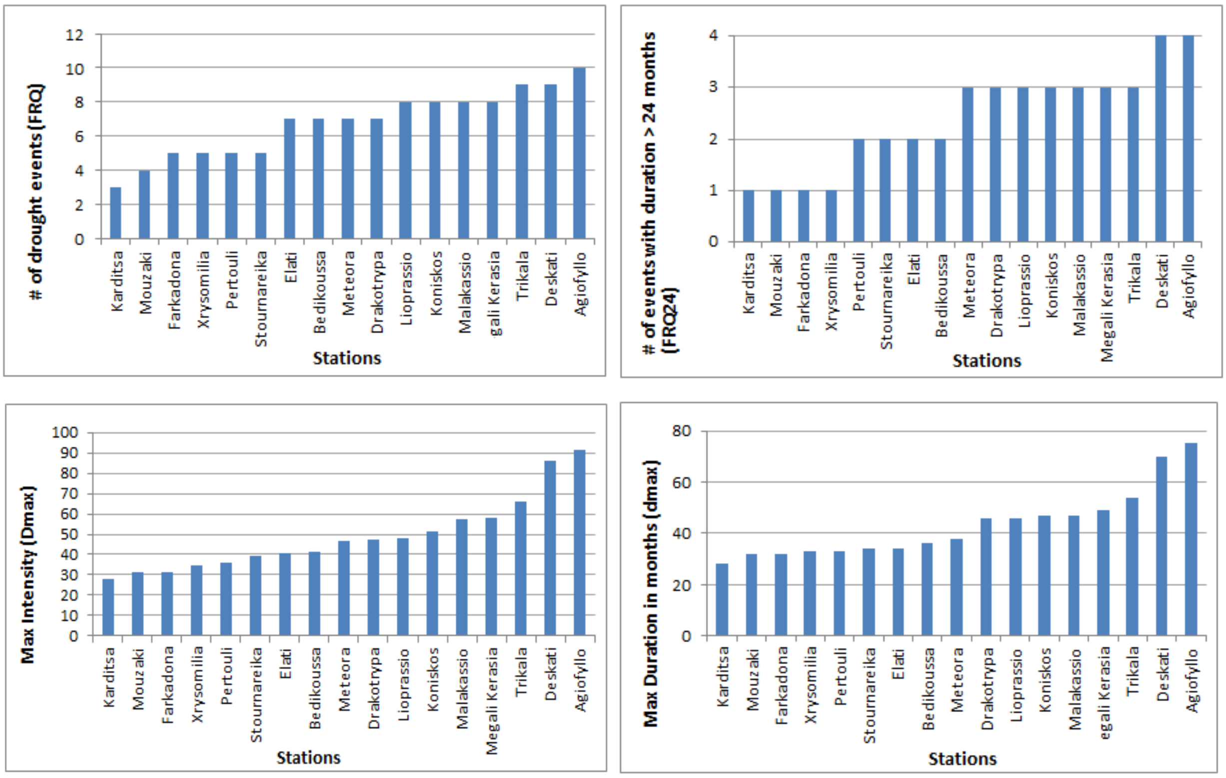


Figure 8.9: Values of the four sub-indicators in each of the 17 rain gauges for the 30-year period 1981-2010.

The results of the respective classification for the period 1981-2010 are demonstrated in Figure 8.10. With regard to the number of drought events (FRQ sub-indicator) in the majority of stations (about 60%) 4-6 events have occurred within the 30 years (thus roughly corresponding to one event every 6 years), while in 35% of them 7-9 events have occurred (thus roughly corresponding to one event every 4 years) (Figure 8.10). Almost half of those events had durations of more than 24 months. In some stations, all, or nearly all, of the events had durations of more than 24 months (100% of the events in Trikala station, 80% in Elati and Stournareika stations). With regard to the maximum drought magnitude (DMmax sub-indicator) in 41% of the locations maximum magnitudes ranged from 35-50, while higher ones occurred in 35% of the locations (Figure 8.10). Finally, the drought events in the majority of the stations (53%) had an observed maximum duration 24-36 months, while 18% of the stations experienced events with more than 60 months duration (Figure 8.10). A comparison of the sub-indicators classification between the sub-periods 1981-1995 and 1995-2010 is also provided in Figure 8.11. Overall, we can observe that the number and the maximum magnitudes of the drought events decrease in the period 1996-2010 as compared to the previous period 1981-1995, yet their durations tend to increase and consequently the number of events with durations of more than 24 months. We can thus conclude that the occurrence of drought episodes may be a bit less frequent and/or intense in terms of magnitude, but they are now longer, and can evolve into prolonged drought of more than 60 months duration.

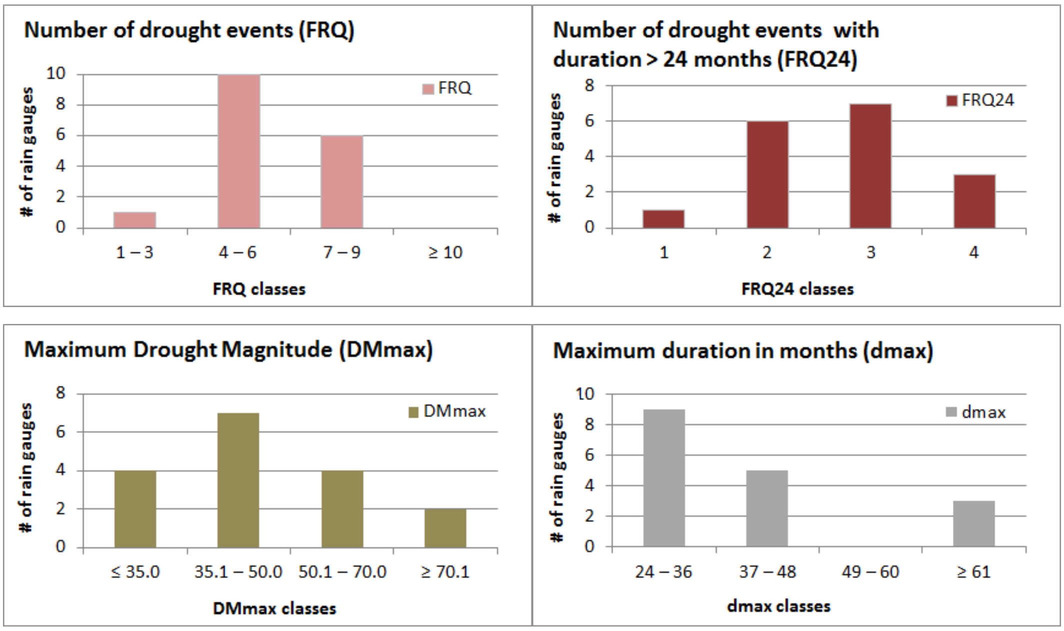


Figure 8.10: Histogram of the four sub-indicators across the 17 rain gauges for the 30-year period 1981-2010. Each class relates to a relevant 1-4 score.

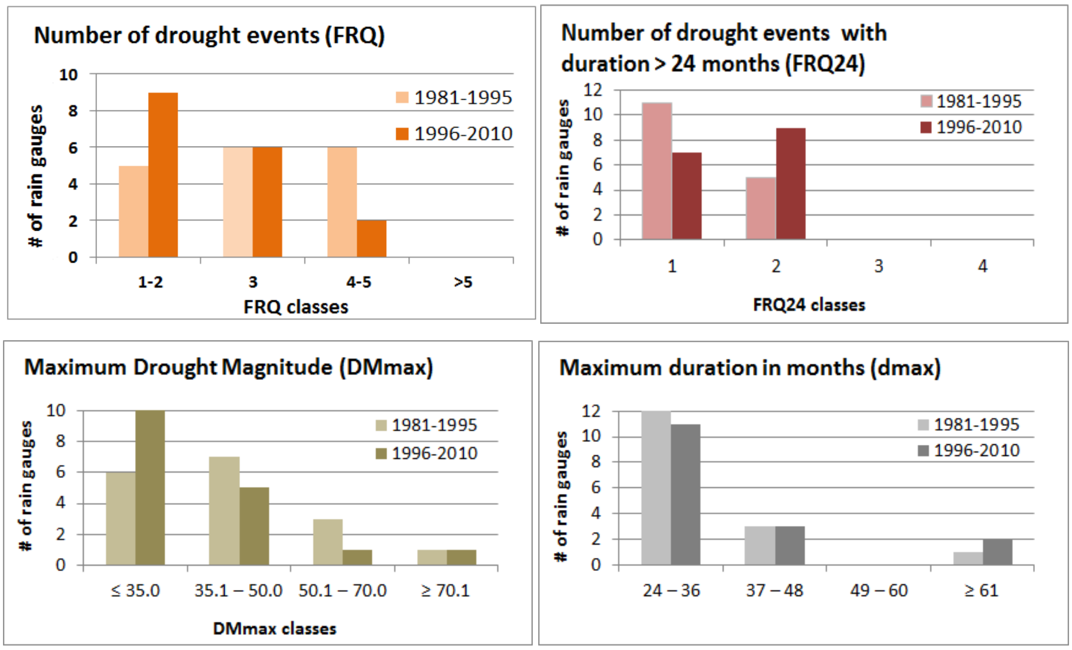


Figure 8.11: Histograms of the four sub-indicators across the 17 rain gauges for the 15-year periods 1981-1995 and 1996-2010. Each class relates to a relevant 1-4 score.

The mapping of the drought hazard in the Ali-Efenti has been based on the interpolation of the DHI values calculated at each rain gauge for the entire 1981-2010 period, as well as for the individual sub-periods 1981-1995 and 1995-2010. The average DHI value across all 17 stations for the period 1980-2010 equals to 2.24, indicating that the Ali-Efenti catchment experiences overall a significant drought hazard (Table 8.6). The maximum DHI value (3.0) is observed in the Agiofyllo and Deskati stations in the north, while the minimum (1.75) in Farkadona and Meteora stations (Figure 8.12). Zones of higher to lower exposure alternate from north to south in an east-west orientation. The zones with the highest DHI (2.00-3.16) prevail in the northern area and the south, while a lower risk zone lies in the center (Figure 8.12).

Table 8.6: DHI statistics across all rain gauges

DHI Statistics (across all rain gauges)	Time Periods			Δchange (%) (from 1996-10 to 1981-95)
	1981-2010	1981-1995	1996-2010	
Average	2.24	1.63	1.53	- 0.10 (- 6%)
St. deviation	0.38	0.42	0.51	+ 0.08 (+ 19%)
Maximum	3.00	2.50	2.75	+ 0.25 (+10%)
Minimum	1.75	0.75	0.75	0.00 (0%)

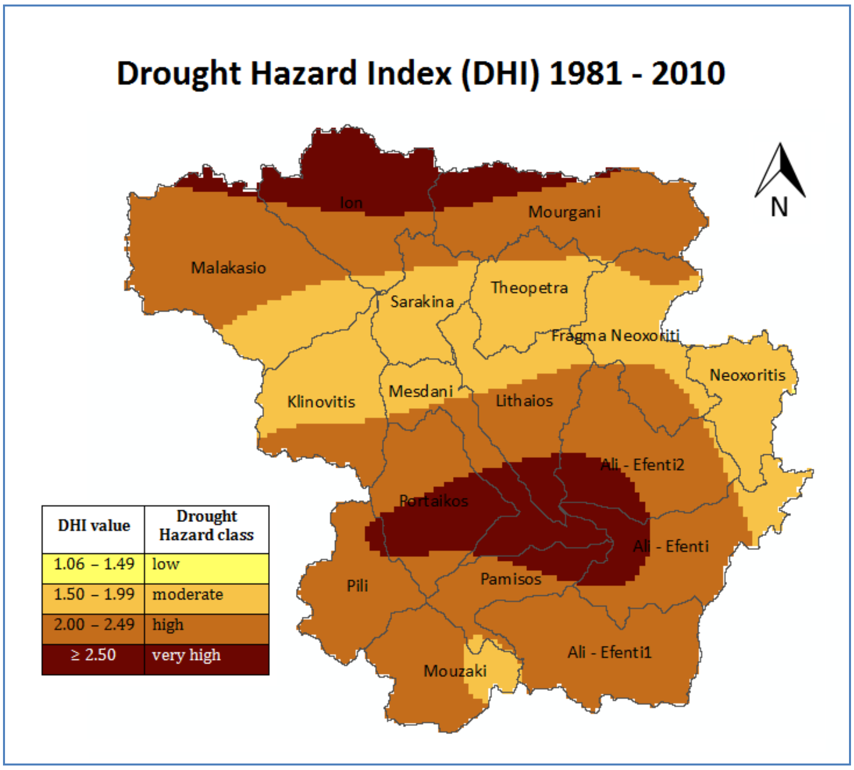
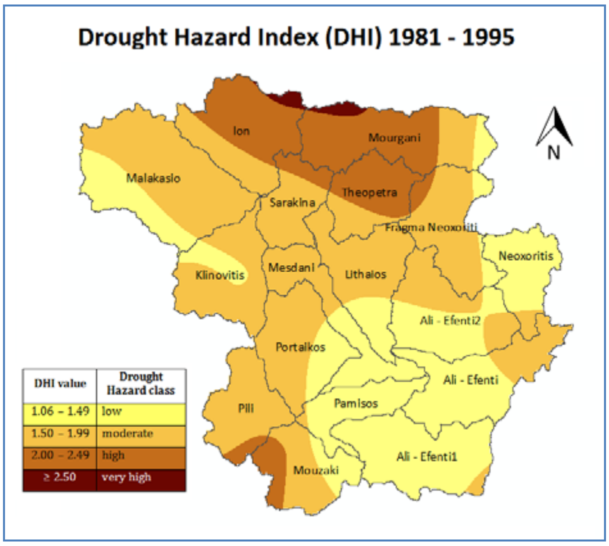


Figure 8.12: Drought hazard map of the Ali-Efenti catchment based on the DHI calculated for the 30-year period 1981-2010.

When comparing the two sub-periods we can observe that the average DHI value across all stations has been slightly reduced by 6% during the 1996-2010 (as compared to the previous 1981-1995 period) (Table 8.6). The maximum observed DHI value in the period 1996-2010 (2.75 currently in Deskati station) is 10% higher than the previously observed maximum during 1981-1995 (2.50 in the nearby Agiofyllo station).

Overall, in 10 stations (i.e. 59% of the stations) the DHI has decreased during the 1996-2010 period, in 4 stations (i.e. 24% of the stations) it has increased (pointing to more serious drought hazard conditions), while in 3 stations it remained constant. The observed decrease in the DHI values in those 10 stations ranged from -14% to -50%, while the increase observed in the 4 stations ranged from +29% to +267% in the Deskati station. What is most interesting to notice is the spatial evolution of the DHI in the area (Figure 8.13). While in the period 1981-1995 the drought hazard was more significant in the northern part of the catchment (DHI > 2) it has now "migrated" to the southern part. Thus, the southeast of the catchment clearly experiences an increased exposure to the drought hazard, while in the north a decreasing trend can be observed. Unfortunately, the area where the DHI has increased coincides with the main irrigation districts of the catchment where a lot of the water is needed for agricultural purposes, thus making them prone to increased water stress conditions.



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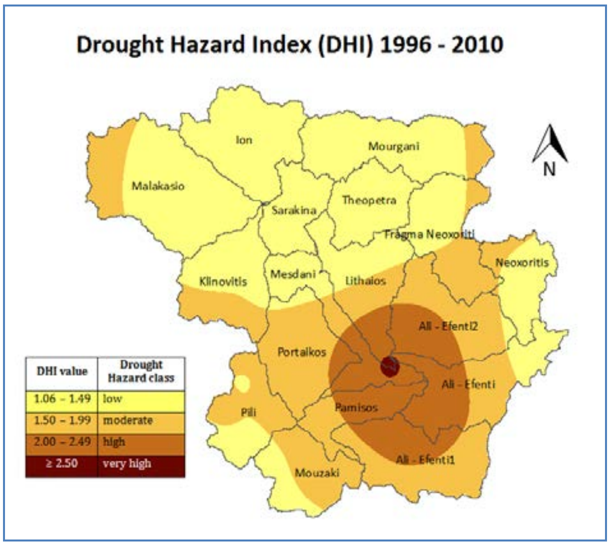
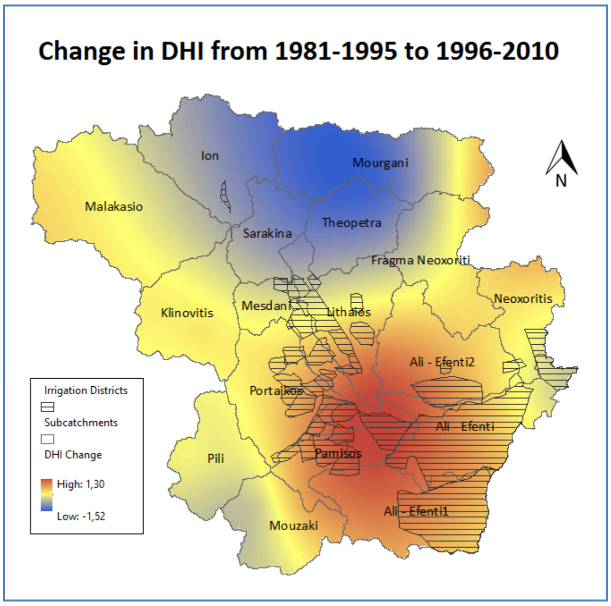


(b)



(c)

Figure 8.13: Evolution of the drought hazard in the Ali-Efenti catchment based on the DHI

(a) drought hazard map for the period 1981-1995, (b) drought hazard map for the period 1996-2010, (c) change of the DHI between the two periods; red areas denote an increase in DHI in 1995-2010 as compared to the previous period 1981-1995).

- Concluding Remarks

The methodology for holistically assessing and mapping drought hazard using the DHI has been tested in the Ali-Efenti catchment (Pinios River Basin) in Greece. The proposed methodology is based on the use of operational indicators, derived from precipitation data, that capture all the drought hazard components: recurrence, severity, magnitude, duration. By post-processing the results of the calculated 12-month Standard Precipitation Index (SPI-12) in 17 rain gauges with precipitation data from 1981-2010 four new sub-indicators have been estimated, reflecting: the number of drought events within the reference period, the number of drought events with a duration larger than 24 months, the maximum intensity of the observed drought episodes, the maximum duration. These sub-indicators have been blended into deriving a Drought Hazard Index (DHI), mapped and classified in the study area. The results show that the Ali-Efenti catchment has experienced significant drought hazards during the years 1981-2010, also verified from discharge observations. In most of the area high values of the DHI are observed (greater than 2.0) indicating substantial exposure to drought. Exposure to drought in 1996-2010 has, as compared to 1981-1995, increased in the southern part of the catchment and decreased in the north. We thus observe a shift in the spatiotemporal evolution of the drought hazard across the two 15-year sub-periods. The observed increase of the DHI in the southern part can relate to increased water stress conditions since this area is dominated by agriculture; higher exposure to drought hazards signals elevated irrigation water needs which can consequently lead to unmet demand and water scarcity in the area.

The use of the DHI in the Ali-Efenti basins has demonstrated that it is an easily reproducible indicator, based on commonly available precipitation timeseries, and flexible enough to be computed for multiple timescales relevant to the drought analysis. It is spatially consistent allowing for comparisons between different areas. It can be calculated for different time periods, permitting thus the assessment of the evolution of drought hazard over time and the detection of trends, while its historic context is suitable for decision making. Finally, the DHI allows for easy integration with additional relevant indicators of environmental or socio-economic context, necessary for the analysis of relevant vulnerabilities and risk (e.g. population density, land use, water exploitation, unmet demand, etc.). It has thus an operational value and could be used to serve policy needs.

8.4 The Water Resources Management Model (WRMM) of Ali-Efenti basin

8.4.1 The WEAP21 Software

The challenge of water management is a matter of growing interest. The allocation of finite water resources between the various agricultural, urban and environmental uses requires an integrated consideration of many factors such as supply, demand, water quality and ecological issues. The WEAP21 (Water Evaluation and Planning System), developed by the SEI Stockholm Environment Institute's US Center (www.sei-international.org), is a Decision Support Platform that incorporates the principles and philosophy of integrated water management resources. It provides the ability to model both the physical and socio-economic system at a highly disaggregated level (if desired), and assists the user in visualizing (through an interactive and user-friendly Graphical User Interface) the system interactions and cause-effect relations, supporting thus the decision making process.

The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; Use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use (SEI, 2015). As such, the WEAP system supports the spatial and temporal definition of the problem, the schematization and modeling of the study area for determining the initial conditions (Current Accounts), the creation and organization of databases, the processing of the raw data, the presentation of the processed information in an understandable and supervisory way, the creation of future scenarios of hydrological change and socio-economic development or management options, and the simulation of these scenarios to assess the impact of each scenario/option on the hydrological, environmental or socio-economic state. Therefore, based on the above, WEAP21 provides to the user the ability to obtain a comprehensive and in-depth perspective on impacts which will result from each decision. The user and decision maker assess these effects and ultimately selects the decision considered closer to their goals. These software capacities are summarized below:

- Water balance database: WEAP provides a system for maintaining water demand and supply information.

- Scenario generation tool: WEAP simulates water demand, supply, runoff, streamflow, storage, pollution generation, treatment and discharge and instream water quality.
- Policy analysis tool: WEAP evaluates a full range of water development and management options, taking into account the various competing uses that participate in a complex water system.

WEAP operates on the basic principle of a water balance and can be applied to urban and agricultural systems, a single watershed or complex transboundary river basin systems. Moreover, it can simulate a broad range of natural and engineered components of these systems, such as: rainfall-runoff, baseflow and groundwater recharge from precipitation, sectoral demand analyses, reservoir operations, hydropower generation, pollution tracking and water quality, water conservation, water rights and allocation priorities, vulnerability assessments, and ecosystem requirements. A financial analysis module also allows the user to investigate cost-benefit comparisons for projects. The analyst represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, reservoirs, and desalination plants), withdrawals, transmission and wastewater treatment facilities, water demands, pollution generation, and ecosystem requirements. The data structure and level of detail can be easily customized to meet the requirements and data availability for a particular system and analysis. The main highlights of the WEAP21 software are presented below (SEI, 2015).

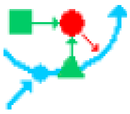
- Integrated water resources planning system
- Built-in models for: rainfall-runoff, infiltration, evapotranspiration, crop requirements and yields, surface water/groundwater interaction, in-stream water quality
- GIS-based, graphical "drag and drop" interface
- Model-building capability with a number of built-in functions
- User-defined variables and equations
- Dynamic links to spreadsheets and other models
- Embedded linear program solves allocation equations
- Flexible and expandable data structures
- Powerful reporting system including graphs, tables and maps

Another important feature of WEAP is the ability to establish dynamic interaction with other models and software such QUAL2K, MODFLOW, MODPATH, PEST, Excel and MATLAB. In the present work WEAP is coupled with MATLAB.

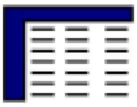
WEAP21 has been used worldwide to support various water resources planning and management applications involving decision-making (http://www.weap21.org/index.asp?action=216). Tsoukalas and Makropoulos (2015) deployed a multi-objective version of the Parameterization-Simulation-Optimization (PSO) framework with WEAP21 as simulation engine inn order to investigate the performance of a future reservoir and to derive optimal operational rules incorporating uncertainty. Giannikopoulou et al. (2015) applied the WEAP21 in Syros island in Greece in order to perform a risk-based assessment of drought and prioritize long-term drought mitigation options. This assessment combines water balance modelling, hazard analysis, and risk and cost effectiveness analysis to allow for an improved understanding of drought-related risks. Hao et al. (2015) integrated the WEAP21 with the SWAT model (Soil and Water Assessment Tool) to model of water supply and demand under management options and climate change scenarios in Chifeng City, China. Yilmaz and Harmancioglu (2010) used WEAP21 in the Gediz River basin, Turkey to simulate and evaluate the performance of possible management alternatives on the basis of 9 indicators representing economic, social and environmental sustainability. The study has delineated the best management alternative on the basis of three different multi-criteria decision making (MCDM) methods, including simple additive weighting (SAW), compromise programming (CP) and technique for order preference by similarity to ideal solution (TOPSIS). The results of the study indicate that the decision on the best alternative is basically independent of the MCDM method used, but slightly sensitive to the weights assigned to the criteria as well as the data used in the analyses. O'Neil and Yates (2011) developed a Dynamic Decision Support System focused on best alternative analysis for water supply and capital improvement planning. In this paper a multi-criteria decision analysis is used, and the WEAP scenario-based planning methods were utilized to evaluate and select alternatives under different combinations of future population and climate projections. Ospina et al. (2011) applied WEAP21 to the Sinú-Caribe river basin in Colombia to create several baseline and adaptation strategy scenarios for water supply, use and demand, and to make projections for the future including the potential impacts of climate change. Optimization scenarios for hydropower generation for the critical months of the year were also generated and show how water resources management strategies can mitigate the adverse effects of climate change.

8.4.2 Modelling within the WEAP21 Software

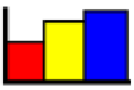
For ease of implementation the WEAP21 has five main "views". These are the schematic, data, results, scenarios explorer and notes views. It also enables the user to create its own data variables, result variables and algebraic expressions. Furthermore, user may define "Key Assumptions", the use of which may be crucial in the modeling process to fine-tune some modelling components and/or simulation processes. Furthermore, the results visualization tools allow creating charts tailored to the needs and preferences of the user. Because of all these features, the WEAP21 is considered as flexible and adaptive to the needs of the user. The five main views of WEAP and their features are described below (SEI, 2015).



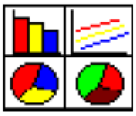
- **Schematic view:** The embedded Geographic Information Systems (GIS) tools allow for a quick and easy display of the system and provide the ability to drag and drop in order to create and place the system components. User can add files in vector format, raster format or other type ArcView GIS as background information at different levels (layers). Fast access to data and results for each system component is possible.



- **Data view**: This is the main place where the user creates the data structures, models and assumptions in WEAP. In the Data View, the screen is divided into four panes. On the top left, a hierarchical tree is used to create and organize data structures under six major categories: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions. The tree is also used to select the data to be edited, which is shown on the right of the screen. For example, clicking on the "Demand Sites" tree branch on the left of the screen, will display the data for all demand sites on the right of the screen. On the bottom left is a data inset schematic. Clicking on an element in the schematic will result in a re-direction of the user to its place on the tree. On the top-right of the screen, a data entry table is used to edit data and create modeling relationships. The information entered here is displayed graphically in the bottom right panel.



- **Results view**: This view provides a wide variety of charts and tables covering each aspect of the system: demand, supply, costs, and environmental loadings. There are three visualization options: Graphs, which is a graphical representation of the results over time; Tables, which is a detailed presentation of the results; Maps, where it is possible to image results over time. It is worth noting also that customizable reports can be viewed for one or more scenarios, and the user is able to export results for a variety of different variables, each time selecting both the units and scenarios he wishes. The most useful charts for the user can be bookmarked for future reference.



- **Scenarios Explorer view:** This view is used to group together "Favorite" charts (created earlier in the "Results" view) into "Overviews" for simultaneous display. The user can thus get a birds-eye perspective on different important aspects of the system, such as demands, coverage, flows, storage levels, environmental impacts and costs. In addition to showing Results, the Scenario Explorer View can display selected Data across many scenarios, to help demonstrate the impact of various assumptions and policies on results. The input values can be changed on the spot and WEAP will recalculate and update the results.

- **Notes view**: This is a simple word processing tool where the user can enter documentation and references for each branch of the tree. It is thus possible to keep and archive notes regarding the data, assumptions used, etc. Editing, printing and exporting functions are available.

To model a system with WEAP generally includes the following steps (SEI, 2015).

- **Study definition**: The time frame, spatial boundaries, system components, and configuration of the problem are established.
- **Current accounts**: A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.
- **Scenarios:** A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored.
- **Evaluation**: The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

The first step in modeling a system within the WEAP21 is the representation of the existing state, i.e. the situation is the year considered as the start of the period of interest. This is done by selecting the “Current Accounts”. The user selects the option

Current Accounts from the menu at the top of the screen, selects the year regarded as the basis of the system and then proceeds to importing all the data and features (natural and technical) for that year. Once the Current Accounts are set, the user can start creating scenarios which represent a future picture of the system and investigate the possible changes that will occur in future years in the system by implementing different policies and strategies. Note that each scenario is completely independent from the others and represents a different future state. The WEAP21 then calculates for each scenario separately the amounts of water that will be provided to every node, respecting each time the current restrictions imposed by each scenario, and the priorities set between nodes. The priorities of nodes in WEAP can take a value between 1-99 values (denoted with 1 the highest and 99 the lowest). The WEAP will try to satisfy all the demands, starting with the distribution of water from nodes with higher priority and then continuing in those with the lowest priority until they meet all demands or until reserves run out, whichever comes first. It is also possible to compare the results of different scenarios, so that a decision maker can easily choose the more efficient and appropriate policies and decisions.

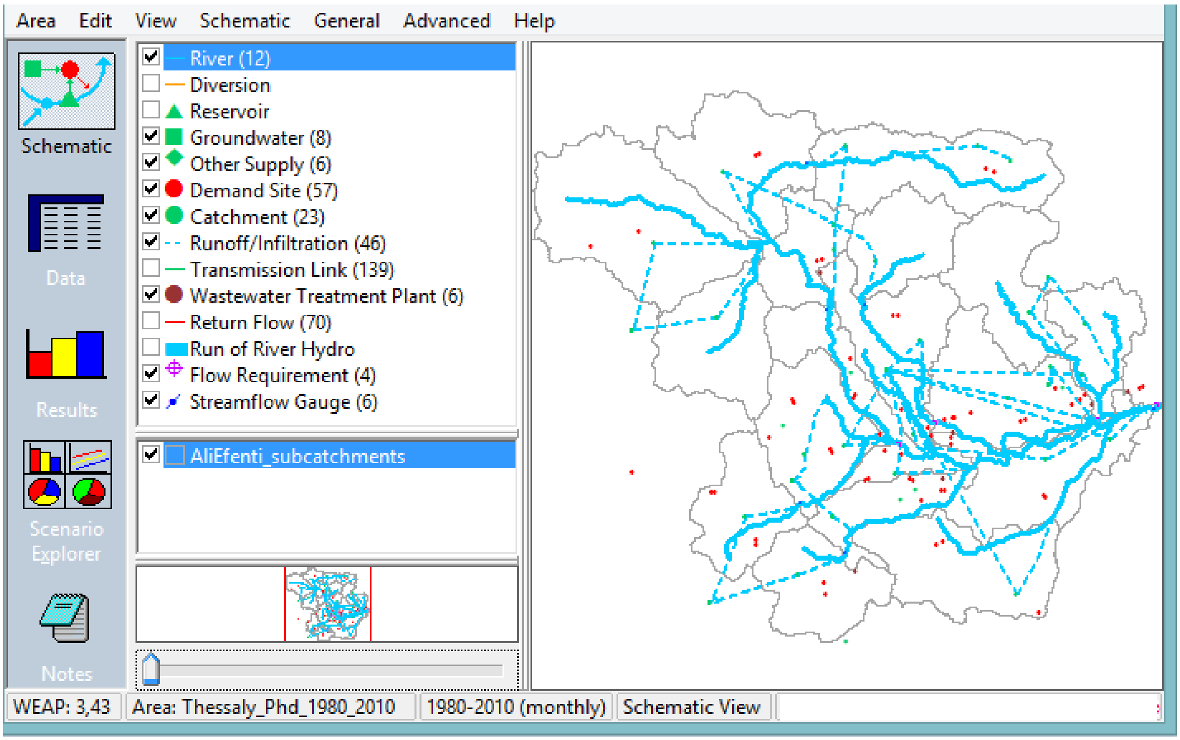


Figure 8.14: Example of Modeled area in WEAP21

8.4.3 The Ali-Efenti Model setup

A detailed water balance model has been set up for the Ali-Efenti River Basin in northeastern Pinios using the WEAP21 software at monthly timestep for the period 1980-2010. The 1980-1994 period has been used for model calibration and validation, while the 1995-2010 period represents the baseline scenario. In order to set up the node-based disaggregated WEAP model, a detailed analysis of the study areas has been implemented to post-process all the data collected and create the necessary input data for the model. A scheme of the model, with all the nodes and their interconnection links is depicted in Figure 8.15. The model comprises of 23 sub-catchments, 8 groundwater bodies, 6 springs, 46 runoff/infiltration links (carrying runoff and infiltration from catchments to rivers and groundwater bodies), 57 demand sites (50 for domestic, irrigation, livestock and industrial water users, and another 7 “dummy” nodes), 6 WWTPs, 139 transmission links (transmitting water from a surface or groundwater withdrawal node to a user), 70 return flow links (directing the water that is not consumed in a demand side to a WWTP, surface or groundwater body). The above elements are illustrated in Figure 8.15.

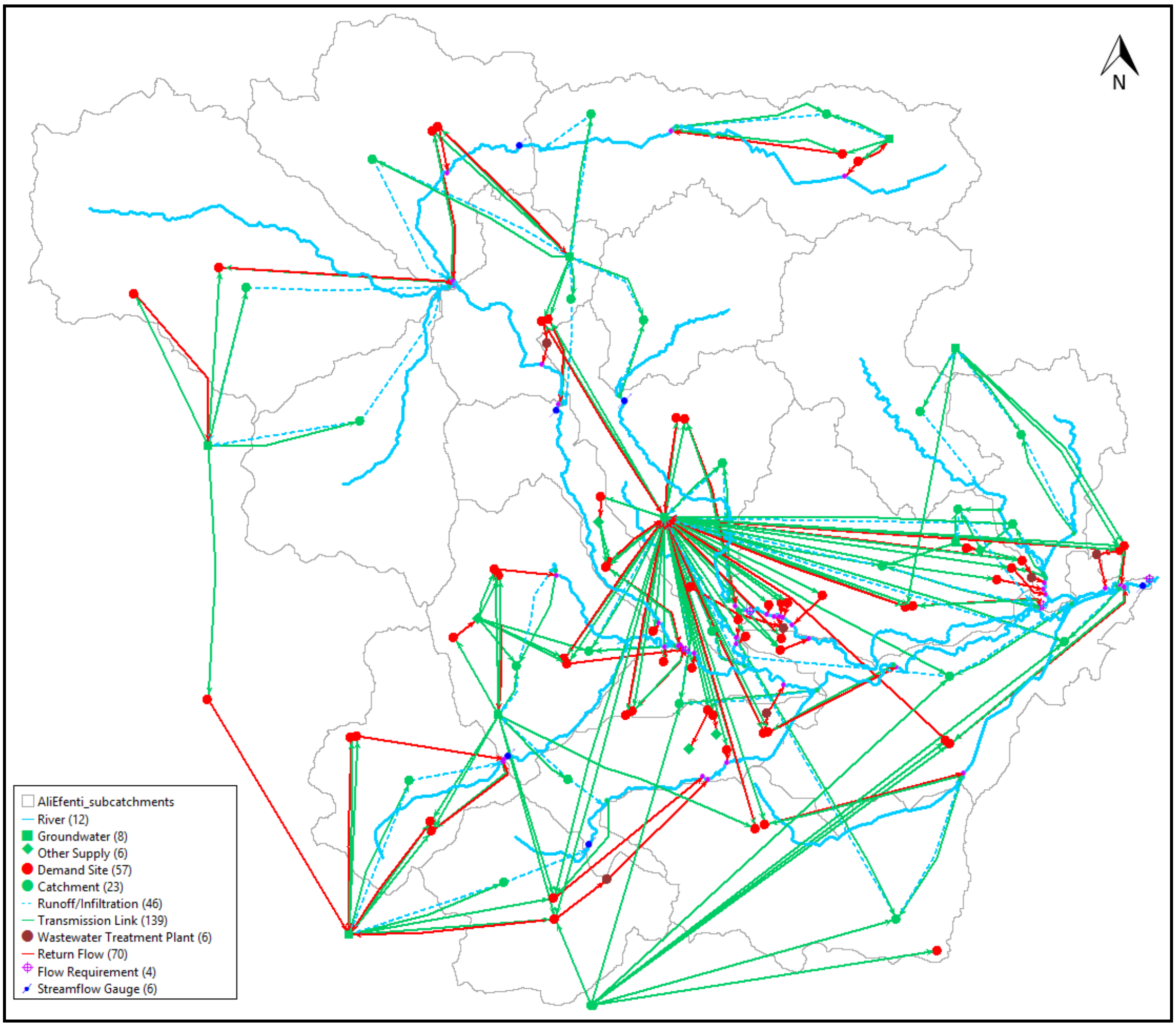


Figure 8.15: Schematic representation of the WEAP model for the Ali-Efenti basin

- **Demand sites and catchments**

The model is set-up around 23 sub-catchments. The water demands sites in the study area are represented in WEAP by 20 domestic/urban demand nodes, 23 irrigation demand nodes implemented within the sub-catchments, 19 livestock demand nodes and 11 industrial nodes, all simulated as "demand sites". In terms of water allocation priorities, meeting domestic water demand has been assigned a priority 1, irrigation and livestock have been assigned a priority 2, while the industry has been assigned a priority 3.

To model the **domestic/urban water demand** the "specify monthly demand" method of WEAP has been chosen, and the demand per node (site) has been inserted as a function of the following parameters:

*Monthly Domestic Demand (m3) = Population[cap]*Population change*Daily Water Use per capita[m^3]*Losses Correction Factor*Seasonal Correction Factor*Month Duration[day]*

Monthly Domestic Consumption = 20% of Monthly Domestic Demand [it represents the % inflow consumed, lost from the system]

Return flow = Inflow(1-consumption)*

Tourism water demand has been added in the Domestic demand in the sites where this was relevant, calculated as follows:

*Tourism annual demand = Tourism_Nights spent[day]*Tourism_Annual Water Use per capita[m^3]*

*Monthly Tourism Demand (m3) = Tourism_Annual Demand[m^3]*Tourism_Monthly Distribution Fraction*Losses Correction Factor*

Table 8.7: Key assumptions (user-defined variable) used in the domestic water demand calculations for the baseline 1995-2010 scenario.

Key Assumption	Value
Daily water use rate	0.17 m^3
Losses correction factor	1/0.6 = 1.67
Sanitation tank containment	10%
Seasonal Correction Factor	0.7 m^3 (Oct-Mar); 1.3 (Apr-Sept)
Population change (scenarios)	x % (1 in the baseline)
Hotel water use rate	0.4 m^3/year
Motel water use rate	0.3 m^3/year
Tourism monthly distribution factor	Monthly Values(Oct; 0,12; Nov; 0,07; Dec; 0,05; Jan; 0,04; Feb; 0,03; Mar; 0,08; Apr; 0,09; May; 0,11; Jun; 0,10; Jul; 0,09; Aug; 0,11; Sep; 0,11)

To model the **industrial water demand** per node (site) a function of the following parameters has been used:

*Monthly Industrial Demand (m3) = Daily Water Use per unit[m^3]*Losses Correction Factor*Seasonal Correction Factor *Month Duration[day]*

Monthly Industrial Consumption = % of Monthly Industrial Demand [it represents the % inflow consumed, lost from the system]

Dairy products = 20%

Meat & oil products = 20%

Structural materials = 94%

Return flow = Inflow(1-consumption)*

Table 8.8: Key assumptions (user-defined variable) used in the industrial water demand calculations for the baseline 1995-2010 scenario.

Key Assumption	Value
Losses correction factor	1/0.6 = 1.67
Seasonal Correction Factor	1

To model the **livestock water demand** per node (site) a function of the following parameters has been used:

*Monthly Livestock Demand (m3) = Population[cap]*Population change*Daily Water Use per cap[m^3]*Losses Correction Factor*Seasonal Correction Factor*Month Duration[day]*

Monthly Domestic Consumption = 70 % of Monthly Industrial Demand [it represents the % inflow consumed, lost from the system]

Return flow = Inflow(1-consumption)*

Table 8.9: Key assumptions (user-defined variable) used in the livestock water demand calculations for the baseline 1995-2010 scenario.

Key Assumption	Value
Daily water use rate Cow; Sheep; Goat; Pig; Horse; Rabbit; Chicken	m^3/day/animal 0.08; 0.008; 0.008; 0.08; 0.036; 0.004; 0.0002
Losses correction factor	1/0.6 = 1.67
Seasonal Correction Factor	0.7 m^3 (Oct-Mar); 1.3 (Apr-Sept)
Population change (scenarios)	x % (1 in the baseline)

To model the **irrigation water demand** per node (site) the irrigation areas (km^2) have been incorporated in the catchment according to crop types (calculation of the areas occupied by each type of crop). The crops included alfalfa, corn, cotton and sugarbeets. Based on the Reference Evapotranspiration (ETref) and the crop coefficient Kc, the potential evapotranspiration PETcrop has been calculated for each crop type. Then, the irrigation need for each crop area has been identified based on the difference between the available precipitation and the PETcrop, and the required supply per crop and area has been determined. Since during the conveyance and application of irrigation on the fields losses do exist, the irrigation supply required is divided by a coefficient (the "irrigation efficiency coefficient") to obtain the final irrigation needs of the crops. To calculate the total supply required in the catchment, all the individual requirement of the crops have been added up. Finally, the supply required has been differentiated per source (% from surface water, groundwater, springs, etc.) based on existing data from the municipalities in the area.

Irrigation Need_crop = Max(0;(PETcrop[mm]-Available Precipitation[mm]))

Supply Required_crop (m^3) *= Area*$[m^2]$**Irrigation Need_crop[mm]/(1000*Irrigation Efficiency Coefficient*

Supply Required_catchment $(m^3) = \Sigma$ *Supply Required_crop* (m^3)

The irrigation efficiency coefficient takes into account the conveyance method (closed pressurized pipe or open channel), and the method of irrigation (drip irrigation, furrow or sprinklers). The assessment of this coefficient, was based on several recent studies for the Ali-Efenti, including Makropoulos and Mimikou (2012), Water Resources Management Consortium of Central & Western Greece, (2005). With regard to the conveyance efficiency values of 60% and 80% are reported for open channels and closed pipes respectively in collective networks, while values of 95% are reported for closed pipes in small individual networks. With regard to the field application efficiency, 90-95% is reported for drip irrigation systems, 80-90% for sprinklers, and 60-75% for furrow irrigation. Table 8.10 below combines the above values into the aggregated irrigation efficiency (conveyance and field application). As seen below, the small individual networks which are drip irrigated have the highest efficiency and that is due to the conveyance efficiency being very high (95%). High efficiency is also noted in new drip irrigated networks.

Table 8.10: Aggregated table for conveyance and irrigation efficiency

Conveyence and Irrigation Efficiency		Drip	Sprinkler	Furrow
Closed Pipes	Collective Networks	76.0%	68.0%	52.0%
	Small individual networks	90.3%	80.8%	61.8%
	New Networks	90.3%	80.8%	61.8%
Open Channels	Collective Networks	57.0%	51.0%	39.0%
	Small individual networks	-	-	-

The data presented above in conjunction with the irrigated land in Thessaly are used to calculate the combined irrigation efficiency of each Prefecture (Karditsa and Trikala) and used as input for the WRMM "Irrigation Efficiency Coefficient" parameter. The results from this procedure are presented below in Table 8.11 and Table 8.12 for Karditsa and Trikala prefectures respectively. Karditsa's combined efficiency in the current situation is estimated to be 75.4% and Trikala's combined efficiency is 77.6%.

Table 8.11: Karditsa Prefecture, current situation

Type of Network/Conveyance Method	Irrigated Land (2004) ha	Land Percent (%)	Percent of Irrigation method			Combined efficiency	Prefecture efficiency
			Drip	Sprinkler	Furrow		
Total	20420						
Collective networks	4288.2	21%					
Closed pipes			9%	14%	0%	0.544	0.754
Open Channels			12%	49%	16%		
Individual networks	16131.8	79%					
Closed pipes			1%	99%	0%	0.808	
Open Channels			0%	0%	0%		

Table 8.12: Trikala Prefecture, current situation

Type of Network/Conveyance Method	Irrigated Land (2004) ha	Land Percent (%)	Percent of Irrigation method			Combined efficiency	Prefecture efficiency
			Drip	Sprinkler	Furrow		
Total	27600						
Collective networks	10212	37%					
Closed pipes			14%	84%	0%	0.687	0.776
Open Channels			0%	0%	2%		
Individual networks	17388	63%					
Closed pipes			22%	78%	0%	0.828	
Open Channels			0%	0%	0%		

The total annual water abstractions of the all the above users, which was applied to the model, is summarized in Table 8.13 below. The share (as percentage of the total abstraction) per sector is illustrated in Figure 8.16. The largest percentage is abstracted for irrigation (~94.5%), followed by abstractions for domestic purposes (~4%), while livestock and industry account only for roughly 1.5% jontly.

Table 8.13: Total annual water abstraction per user category in the Ali-Efenti basin

Year	Abstraction for Irrigation (mio m³)	Abstraction for Domestic use (mio m³)	Abstraction for Livestock use (mio m³)	Abstraction for Industry (mio m³)	Total Abstraction (mio m³)
1995	453.45	19.83	6.10	2.19	481.57
1996	471.21	19.83	6.10	2.19	499.33
1997	482.75	19.83	6.10	2.19	510.87
1998	495.60	19.83	6.10	2.19	523.72
1999	490.85	19.83	6.10	2.19	518,.97
2000	507.66	19.83	6.10	2.19	535.78
2001	505.51	19.83	6.10	2.19	533.63
2002	466.03	19.75	6.10	2.19	494.07
2003	470.51	19.69	6.10	2.19	498.49
2004	489.25	19.62	6.10	2.19	517.16
2005	484.50	19.55	6.10	2.19	512.34
2006	480.88	19.48	6.10	2.19	508.65
2007	488.57	19.41	6.10	2.19	516.27
2008	487.43	19.34	6.10	2.19	515.06
2009	487.04	19.27	6.10	2.19	514.60
2010	475.52	19.22	6.10	2.19	503.03
TOTAL	7,736.76	314.14	97.60	35.04	**8,183.54**

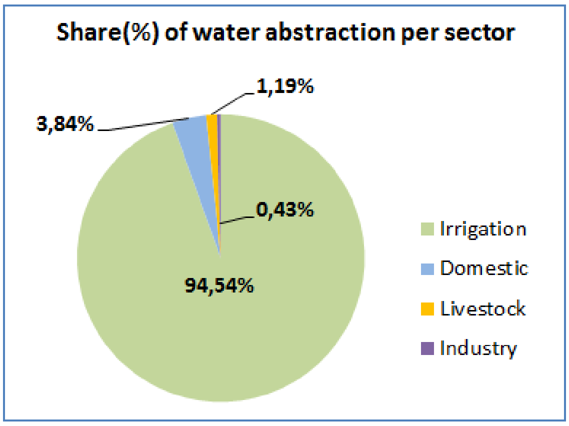


Figure 8.16: Share of water abstraction per sector

- **Hydrological modeling,**

The catchment processes in the model, such as evapotranspiration, runoff, infiltration, etc., have been simulated using the FAO Rainfall-Runoff (RR) method which requires the land use and climate of the catchment site. Land use consists of three parameters: area, crop coefficient (as discussed in FAO Irrigation and Drainage Paper N°56, Allen et al., 1998) and effective precipitation, while climate is defined by the precipitation and the reference evapotranspiration (Penman-Monteith equation). The RR method determines evapotranspiration for irrigated and rainfed crops using crop coefficients. Irrigation demand that may be required to fulfill that portion of the evapotranspiration requirement that rainfall cannot meet is then determined (as described previously). The remainder of rainfall not consumed by ET is simulated as runoff to the river, or proportioned among runoff to the river and flow to groundwater via catchment links. The detailed calculation algorithms of the RR method are presented in Box 8.1.

Box 8.1: Calculation Algorithms used in the Rainfall-Runoff (RR) method

Calculation Algorithms used in the Rainfall-Runoff (RR) method

Crop requirements are calculated assuming a demand site with simplified hydrological and agro-hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Non-agricultural land classes can be included as well. The following equations were used to implement this approach where subscripts LC is land cover, HU is hydro-unit, TS is timestep (e.g., month), I is irrigated, and NI is non-irrigated:

- $PrecipAvailableForET_{LC} = Precip_{HU} * Area_{LC} * 10^{-5} * PrecipEffective_{LC}$
- $ETpotential_{LC} = ETreference_{HU} * Kc_{LC} * Area_{LC} * 10^{-5}$
- $PrecipShortfall_{LC,I} = \mathrm{Max}\ (0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I})$
- $SupplyRequirement_{LC,I} = (1 / IrrFrac_{LC,I}) * PrecipShortfall_{LC,I}$
- $SupplyRequirement_{HU} = \Sigma_{LC,I}\ SupplyRequirement_{LC,I}$

The above four equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapotranspiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

Based on the system of priorities, the following quantities can be calculated:

- $Supply_{HU}$ = Calculated by WEAP allocation algorithm
- $Supply_{LC,I} = Supply_{HU} * (SupplyRequirement_{LC,I} / SupplyRequirement_{HU})$
- $ETActual_{LC,NI} = \mathrm{Min}\ (ETpotential_{LC,NI}, PrecipAvailableForET_{LC,NI})$
- $ETActual_{LC,I} = \mathrm{Min}\ (ETpotential_{LC,I}, PrecipAvailableForET_{LC,I}) + IrrFrac_{LC,I} * Supply_{LC,I}$
- $EF_{LC} = \Sigma_{TS} ETActual_{LC} / \Sigma_{TS} ETpotential_{LC}$

As a result, the actual yield can be calculated with the following equation:

- $ActualYield_{LC} = PotentialYield_{LC} * \mathrm{Max}\ (0, (1 - YieldResponseFactor_{LC} * (1 - EF_{LC})))$
- $Yield_{LC} = ActualYield_{LC} * Area_{LC}$
- $MarketValue_{LC} = Yield_{LC} * MarketPrice_{LC}$

In the Rainfall Runoff method, runoff to both groundwater and surface water can be calculated with the following equations:

- $Runoff_{LC} = \mathrm{Max}\ (0, PrecipAvailableForET_{LC} - ETpotential_{LC}) + (Precip_{LC} * (1 - PrecipEffective_{LC})) + (1 - IrrFrac_{LC,I}) * Supply_{LC,I}$
- $RunoffToGW_{HU} = \Sigma_{LC}\ (Runoff_{LC} * RunoffToGWFraction_{LC})$
- $RunoffToSurfaceWater_{HU} = \Sigma_{LC}\ (Runoff_{LC} * (1 - RunoffToGWFraction_{LC}))$

Units and definitions for all variables above are:

Area [HA] - Area of land cover
Precip [MM] - Precipitation
PrecipEffective [%] - Percentage of precipitation that can be used for evapotranspiration
PrecipAvailableForET [MCM] - Precipitation available for evapotranspiration
Kc [-] - crop coefficient
ETreference [MM] - Reference crop evapotranspiration
ETpotential [MCM] - Potential crop evapotranspiration
PrecipShortfall [MCM] - Evapotranspiration deficit if only precipitation is considered
IrrFrac [%] - Percentage of supplied water available for ET (i.e. irrigation efficiency)
SupplyRequirement [MCM] - Crop irrigation requirement
Supply [MCM] - Amount supplied to irrigation (calculated by WEAP allocation)
EF [-] - Fraction of potential evapotranspiration satisfied, averaged over the season (Planting Date to Harvest Date)
YieldResponseFactor [-] - Seasonal factor that defines how the yield changes when ETActual is less than ETPotential (water stress)
PotentialYield [KG/HA] - The maximum potential yield given optimal supplies of water
ActualYield [KG/HA] - The actual yield given the available evapotranspiration
Yield [KG] - Actual yield for the land class
MarketPrice [$/kg] - Unit value of the crop
MarketValue [$] - Total value of the crop for the land class
RunoffToGWFraction [-] - Fraction of runoff that goes to groundwater
RunoffToGW [MCM] - Runoff to groundwater supplies
RunoffToSurfaceWater [MCM] - Runoff to surface water supplies

Source: Stockholm Environment Institute (SEI), 2015. WEAP Water Evaluation And Planning System. User Guide for WEAP 2015, August 2015.

8.4.4 Calibration and validation procedure

The purpose of the calibration was to achieve a better representation of the catchment physical processes. The selected parameters to be calibrated are the "% of effective precipitation", the "infiltration fraction" per catchment, and the "groundwater outflow" from the river bed to the groundwater. The exact values of these parameters present some uncertainty in the model due to the simplified RR model used within the WEAP which lacks snow accumulation and snowmelt routines, and the presence of karstic aquifers in the basin and associated lag-time in their discharge through the springs. The model has been overall calibrated for the period 1980-1992, using observed streamflow data at 6 gauging stations (the period of calibration varies among the stations) (Figure 8.17). The objective function to maximise was selected to include three goodness-of-fit metrics, namely: the efficiency E (Nash-Sutcliffe), the correlation factor r, and the BIAS, defined as follows:

$$r = \frac{\sum (Q_{obs} - \overline{Q}_{obs}) \cdot (Q_{sim} - \overline{Q}_{sim})}{\sqrt{\sum (Q_{obs} - \overline{Q}_{obs})^2 \cdot \sum (Q_{sim} - \overline{Q}_{sim})^2}} \qquad (1)$$

$$E = 1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \overline{Q}_{obs})^2} \qquad (2)$$

$$BIAS = \frac{\overline{Q}_{sim} - \overline{Q}_{obs}}{\overline{Q}_{obs}} \qquad (3)$$

Where, Q_{obs} and Q_{sim} are the observed and simulated values respectively.

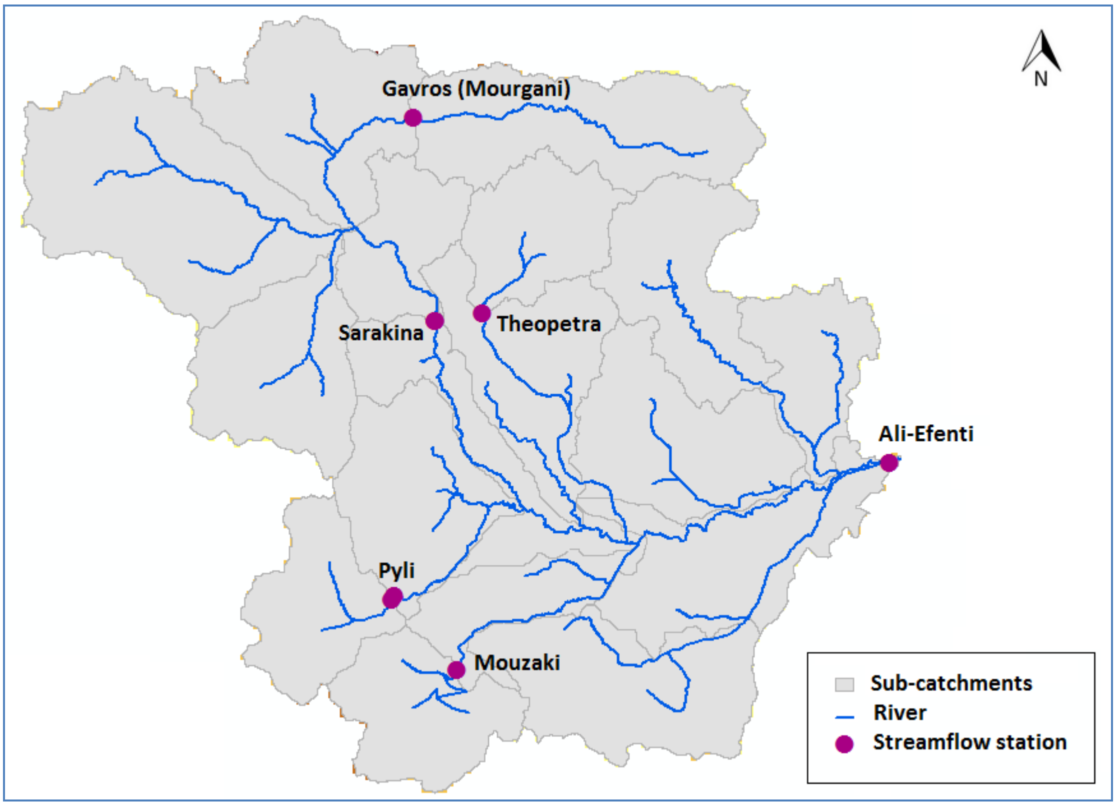


Figure 8.17: The streamflow stations used in the model calibration

The results of the calibration are presented in Table 8.14 and Figure 8.18. It was mainly concluded that the model overestimates winter streamflow and underestimates spring streamflow, thus not accurately capturing the role of the snow accumulation/snowmelt in the basin and the associated runoff lag time. Based on the new calibrated parameters the model was accordingly tuned and adopted to better represent the physical process.

Table 8.14: Goodness-of-fit parameters from the calibration process comparing streamflow at the 6 gauges.

Gauge station	Calibration period	E	r	BIAS
Pyli	11/1986 - 09/1990	0.632	0.802	-0.108
Mouzaki	02/1988 - 09/1992	-0.008	0.545	-0.023
Gavros (Mourgani)	10/1980 - 09/1988	0.680	0.801	-0.040
Sarakina	10/1981 - 09/1988	0.607	0.780	0.020

Theopetra	10/1981 - 09/1988	-0.094	0.039	-0.514
Ali Efenti	06/1981 - 09/1984	0.640	0.810	-0.114

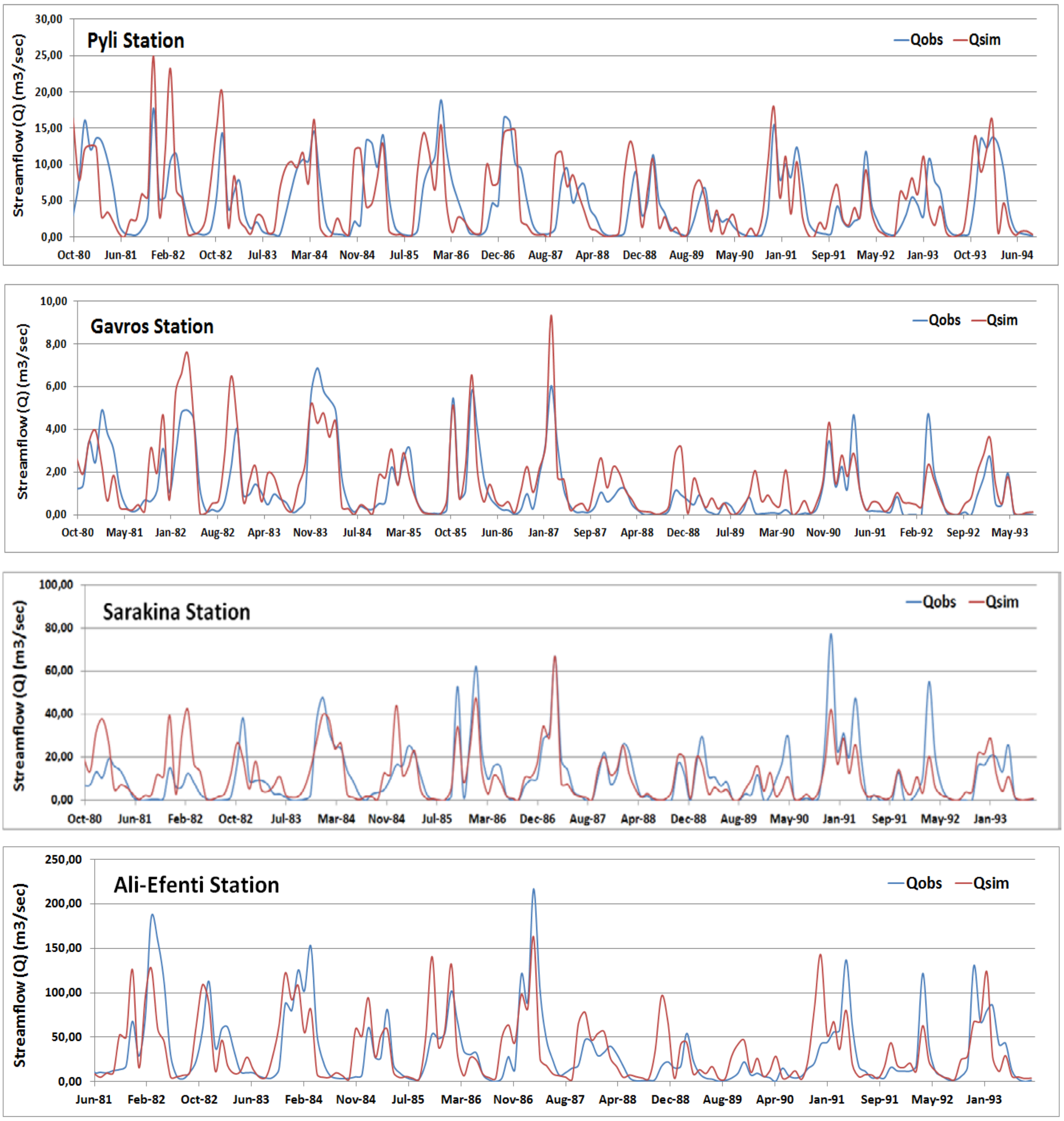


Figure 8.18: Comparison of observed versus simulated streamflows at the gauges of Pyli, Gavros, Sarakina and Ali-Efenti.

To further assess the calibration results the model has been validated for the period 1988-1994, using observed streamflow data at the 6 gauging stations (the period of verification varies among the stations). The same three goodness-of-fit metrics, used during the calibration process, have been evaluated. The results, presented in Table 8.15, showed an improvement of the goodness-of-fit between the observed and the simulated streamflows in all 6 stations (Figure 8.18). In some stations (e.g. Mouzaki) the improvements were significant.

Table 8.15: Goodness-of-fit parameters at the points from the verification process comparing streamflows at the 6 gauges.

Gauge station	Validation period	E	r	BIAS
Pyli	10/1990 - 9/1993	0.639	0.811	-0.133
Mouzaki	10/1992 - 9/1994	0.565	0.802	-0.309
Gavros (Mourgani)	10/1988 - 9/1993	0.650	0.820	0.197
Sarakina	10/1988 - 9/1993	0.680	0.875	-0.201
Theopetra	10/1988-9/1993	-0.088	0.161	-0.683
Ali Efenti	10/1984 - 9/1993	0.595	0.790	0.078

8.4.5 Results and output

A detailed water balance model has been developed for the Ali-Efenti basin in Pinios, allowing the representation of the components of the hydrological cycle and catchment process along with the water demand and use aspects in the catchment. All model features have been calculated at monthly timestep, for each of the 23 sub-catchments and 50 demand sites, allowing the identification of opening and closing stock, and exchange in flows. The inflows and outflows for the entire basin per year are illustrated in Table 8.16, while Figure 8.19 to Figure 8.21 present the inflows and outflows per sub-catchment for the dry year 2007, the normal year 1997 and the wet year 2010.

Table 8.16: Land Class Inflows and Outflows (mio m3) per year for the Ali-Efenti basin

Year	Precipitation	Actual Evapotranspiration	Flow to Groundwater	Surface Runoff	Irrigation
1995	2,939	-833.33	-888.23	-1,619	401.62
1996	2,773	-718.82	-879.44	-1,588	413.4
1997	2,503	-645.77	-820.72	-1,447	410.56
1998	2,714	-686.83	-876.05	-1,571	420.01
1999	2,939	-670.63	-919.31	-1,766	416.71
2000	2,083	-635.03	-673.81	-1,216	441.56
2001	1,689	-640.66	-527.55	-953.6	432.54
2002	2,371	-803.89	-698.73	-1,277	408.54
2003	2,837	-745.52	-882.98	-1,614	406.14
2004	2,271	-638.22	-707.18	-1,300	374.63

2005	2,099	-663.94	-636.99	-1,167	368.84
2006	2,887	-806.23	-896.16	-1,608	422.96
2007	1,469	-579.68	-431.93	-790.77	333.74
2008	2,085	-661.59	-631.26	-1,160	367.11
2009	2,483	-692.32	-785.31	-1,433	427.52
2010	3,320	-834.13	-1045.91	-1,859	419.39
LTAA	**2,466**	**-704**	**-769**	**-1,398**	**404**

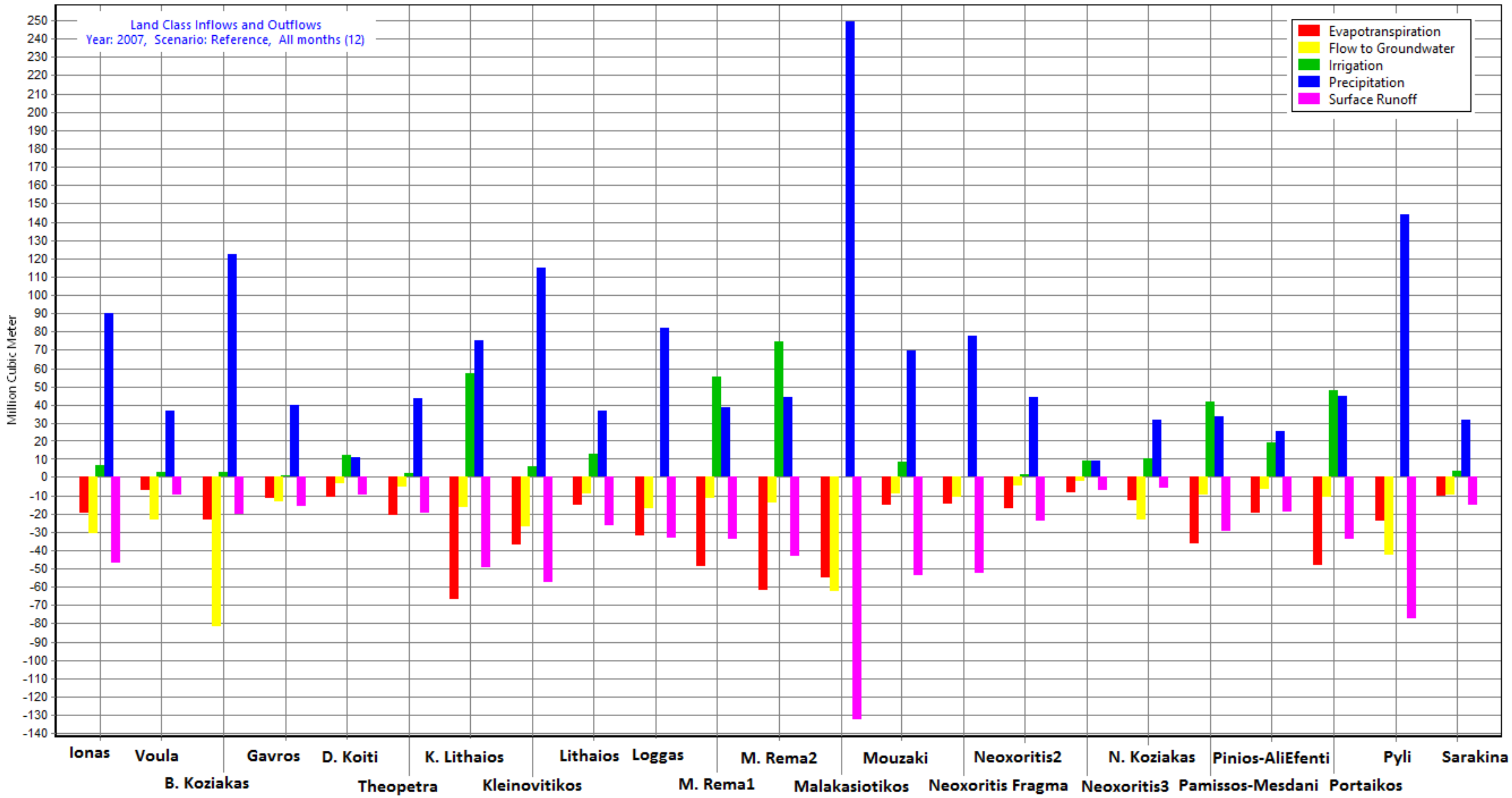


Figure 8.19: Land Class Inflows and Outflows (mio m3) for the dry year 2007 in the sub-catchments of the Ali-Efenti basin

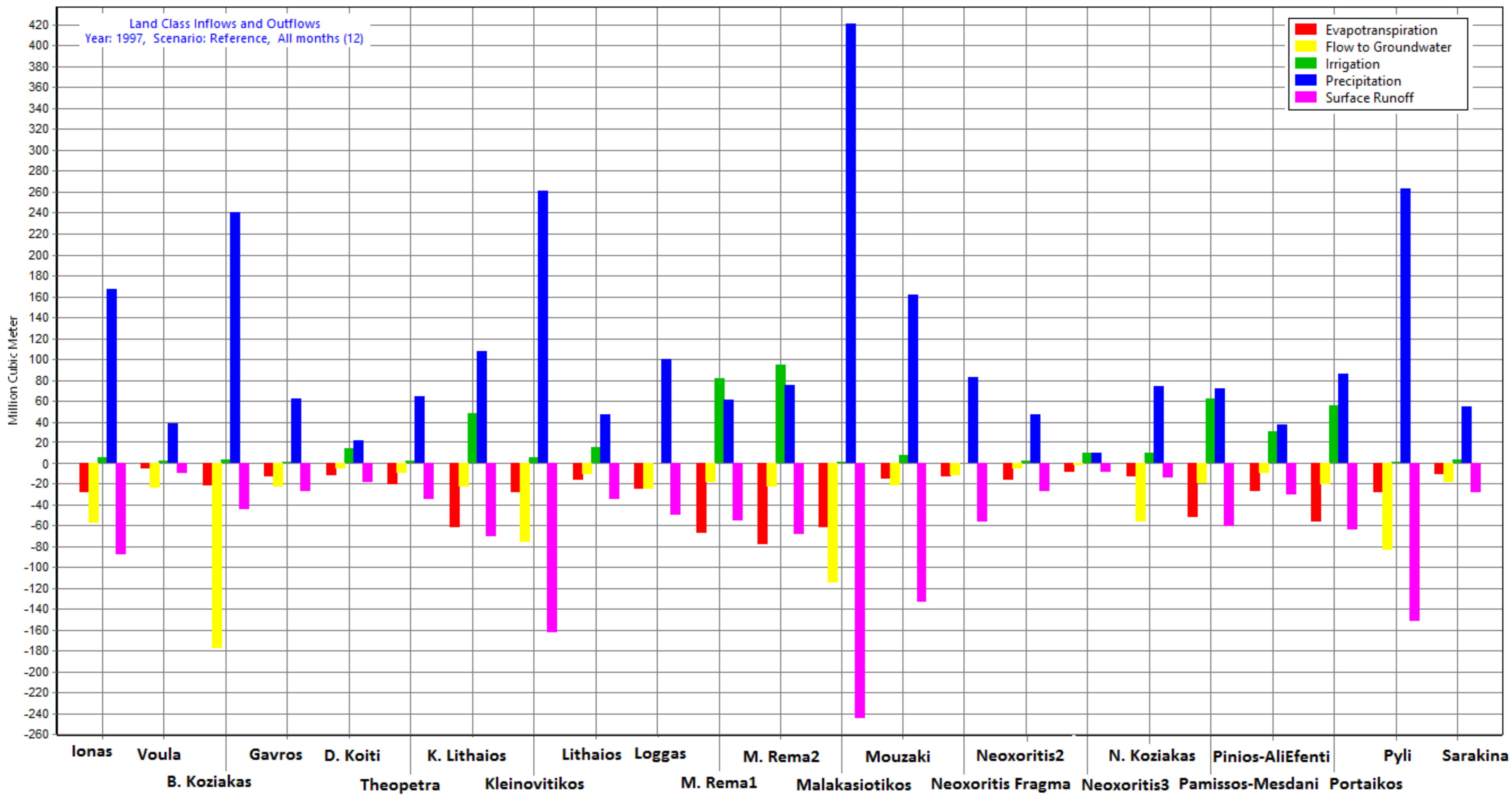


Figure 8.20: Land Class Inflows and Outflows (mio m3) for the normal year 1997 in the 23 sub-catchments of the Ali-Efenti basin

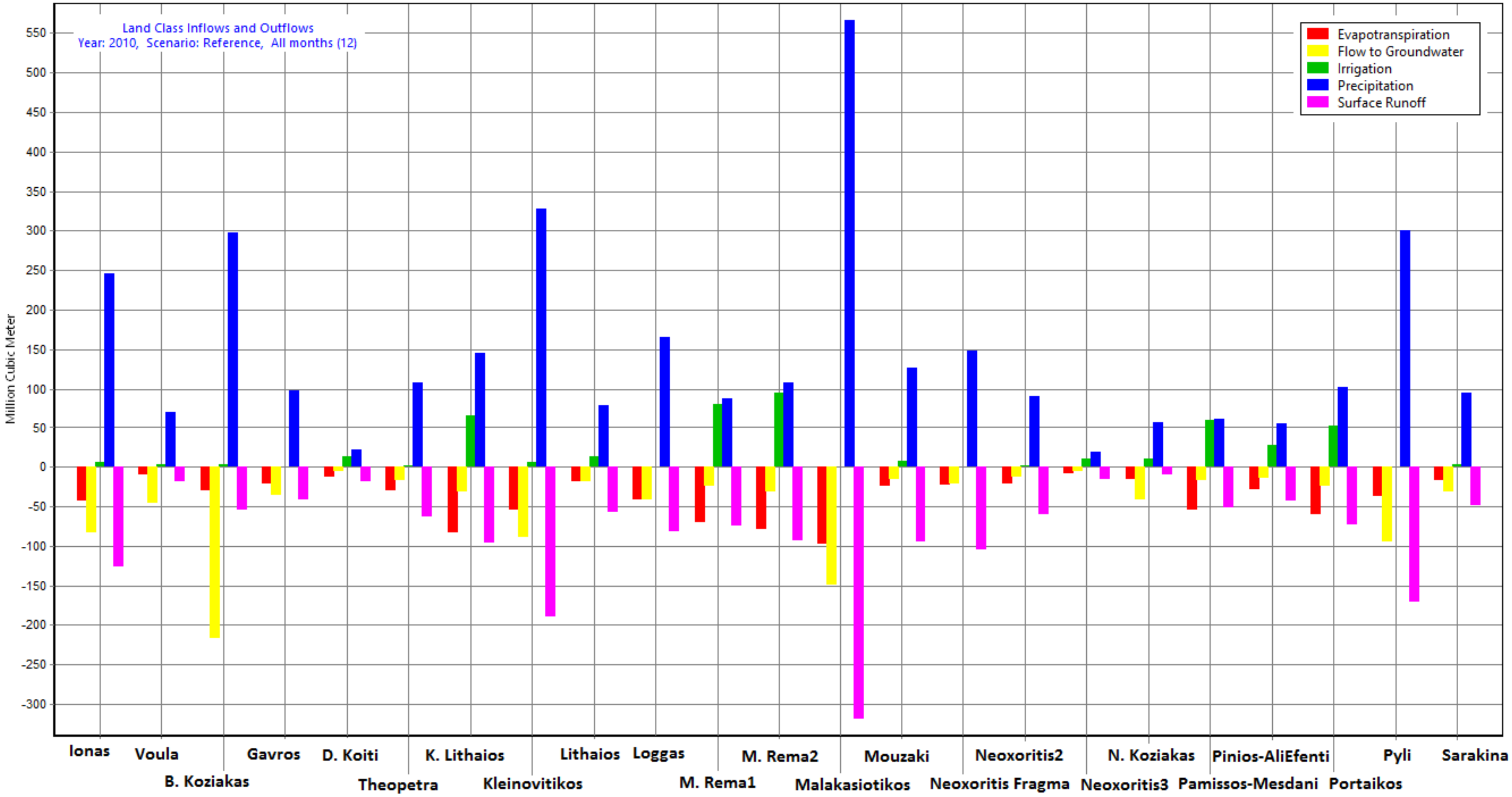


Figure 8.21: Land Class Inflows and Outflows (mio m3) for the wet year 2010 in the 23 sub-catchments of the Ali-Efenti basin

Based on the model results the balance between demand and availability is negative, resulting in unmet demand in all the 23 sub-catchments every year, mainly for irrigation purposes. Unmet demand for industrial and livestock activities has also occurred during the years 2004-2008 but at a much lower level than in irrigation. The total annual unmet demand in the Ali-Efenti Basin is presented in Table 8.17. It ranges from as low as 5 mio m^3 (in 1995) to as high as 114 mio m^3 (in 2007), with an average value of 33 mio m^3 over the 16-year period 1995-2010. The years with the largest unmet demand are 2007, 2008, 2004, 2005. This unmet demand is mainly attributed to irrigation, yet the industry and livestock sectors are also affected during some years (Figure 8.22 to Figure 8.24).

Table 8.17: Unmet demand (mio m3) per year in the Ali-Efenti basin

Year	Total Supply Delivered (mio m^3)	Total Demand (mio m^3)	Total Unmet Demand (mio m^3)	Unmet Demand as % of Total demand
1995	476.65	481.57	4.92	1,02%
1996	489.16	499.33	10.18	2,04%
1997	483.39	510.87	27.47	5,38%
1998	494.44	523.72	29.30	5,59%
1999	490.44	518.97	28.52	5,50%
2000	519.46	535.78	16.31	3,04%
2001	508.02	533.63	25.62	4,80%
2002	483.82	494.07	10.25	2,07%
2003	479.53	498.49	18.97	3,81%
2004	446.36	517.16	70.79	13,69%
2005	442.35	512.34	70.02	13,67%
2006	500.47	508.65	8.21	1,61%
2007	402.39	516.27	113.96	**22,07%**
2008	436.75	515.06	78.34	15,21%
2009	504.13	514.60	10.47	2,03%
2010	495.64	503.03	7.38	1,47%
SUM	**7,653.00**	**8,183.54**	**530.71**	**6,49%**
Average	**478.30**	**511.50**	**33.17**	**6,49%**

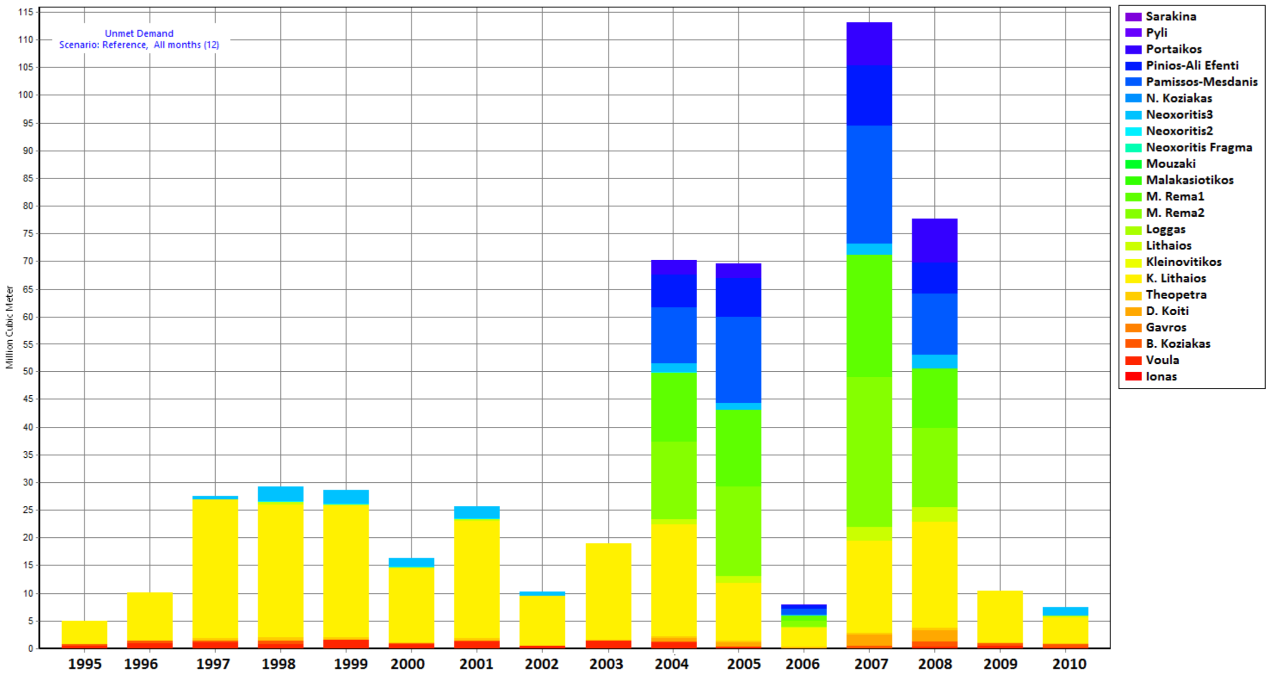


Figure 8.22: Unmet demand (mio m^3) for irrigation per year (from 1995-2010) in the 23 sub-catchments of the Ali-Efenti basin

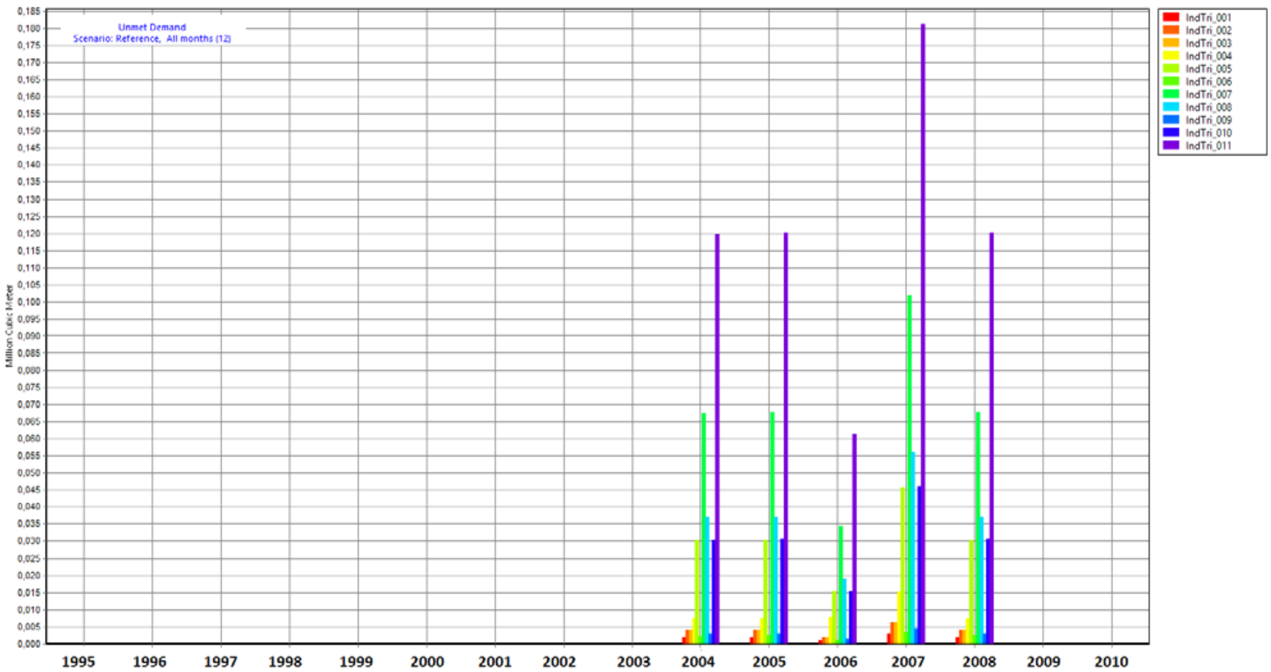


Figure 8.23: Unmet demand (mio m^3) for industry per year (from 1995-2010) in the Ali-Efenti basin

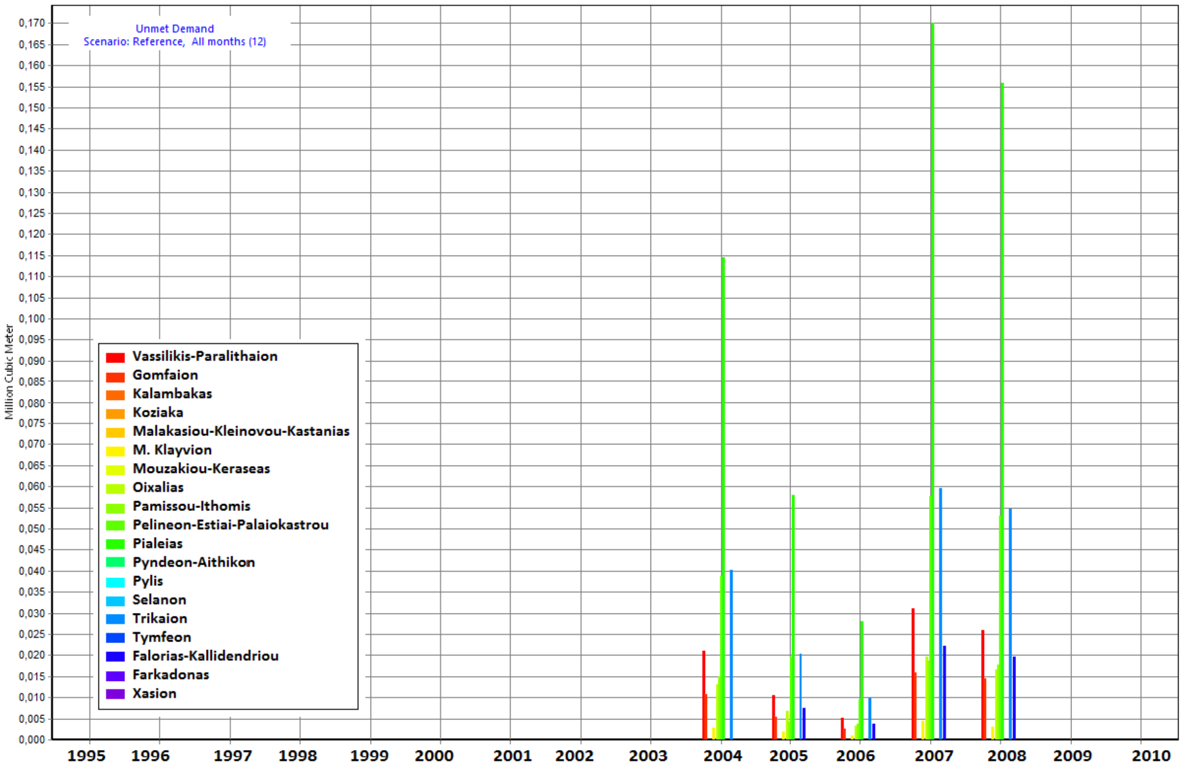


Figure 8.24: Unmet demand (mio m³) for livestock per year (from 1995-2010) in the Ali-Efenti basin

The Reliability of the system in supplying the requested demand ranges among the uses. Reliability is defined as the percent of the timesteps in which a demand site's demand was fully satisfied. For example, if a demand site has unmet demands in 6 months out of a 10-year scenario, the reliability would be (10 * 12 - 6) / (10 * 12) = 95%. As domestic use is priority 1, the water allocation to this use has a reliability of 100%. Reliability in the provision of water to the livestock sector is a bit lower around 96% and for the industry around 97%. Yet, the reliability in irrigation water supply highly varies and is some cases as low as 70% (e.g. for K. Lithaios and B. Koziakas sub-catchments) (Figure 8.25). Table 8.18 summarizes the number of sites (nodes) per water use that fall under different reliability categories. The reliability categories have been defined as very high (>97%), high (90-97%), medium (75-90%) and low (<75%).

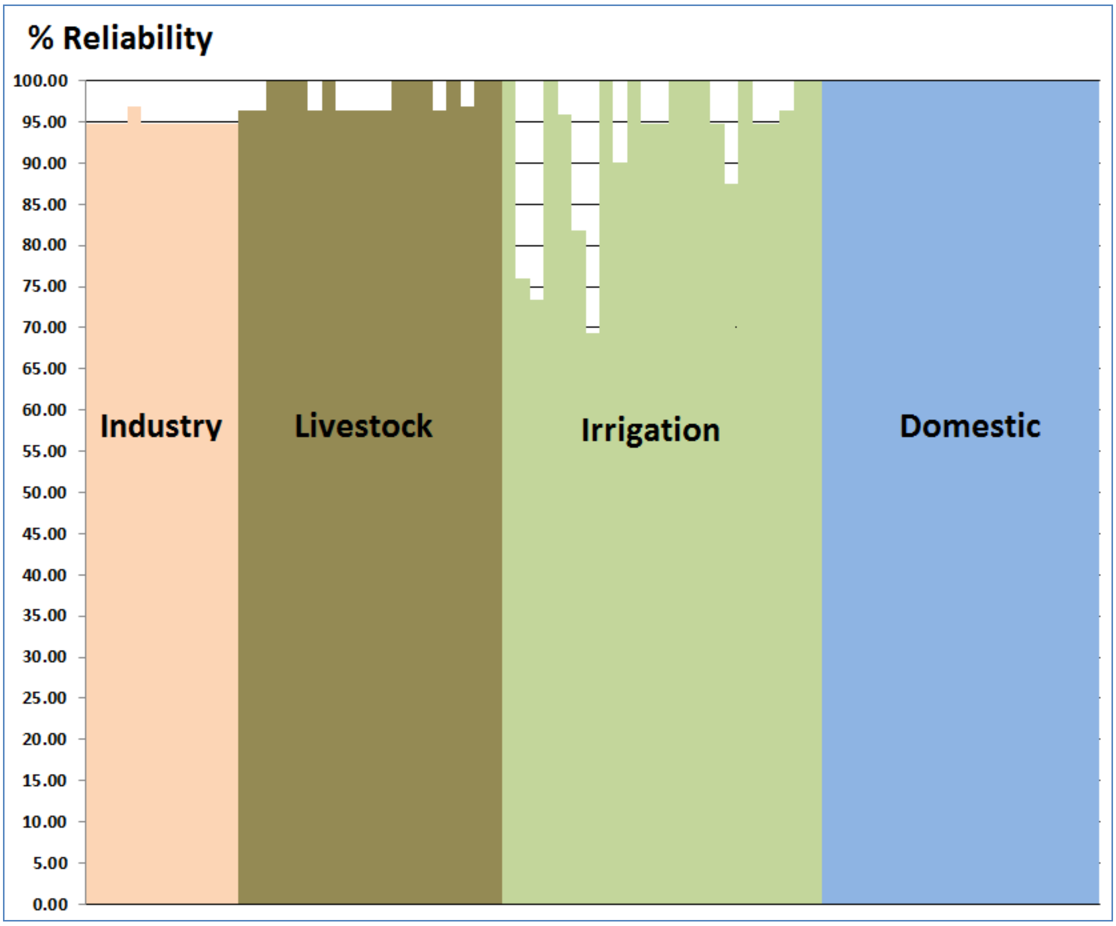


Figure 8.25: Reliability (%) of each demand site of the different user categories in the Ali-Efenti basin

Table 8.18: Percent (%) of user for each use category (domestic, industry, livestock, irrigation) that fall under the 4 reliability classes (low, medium, high, very high) for the 16-year period 1995-2010

Reliability	Domestic users	Livestock users	Industrial users	Irrigation users
Very High (>97%)	100%	53%		43.5%
High (90-97%)		47%	100%	34.8%
Medium (75-90%)				13.0%
Low (<75%)				8.7%

8.5 Vulnerability and Risk Profile of Ali-Efenti basin

To assess the vulnerability and risk profile of the Ali-Efenti basin, the Drought Vulnerability Index (DVI) and the Drought Risk Index (DRI) have been calculated as described in Chapter 4, for the different sub-catchments within the Ali-Efenti and for the reference periods 1981-2010, 1981-1995 and 1995-2010. The 23 modeling sub-catchments used in the WEAP WRMM have been aggregated into 17 to allow for a better representation of vulnerability and risk at the management level, considering the prevailing socio-economic and water allocation settings (Figure 8.26).

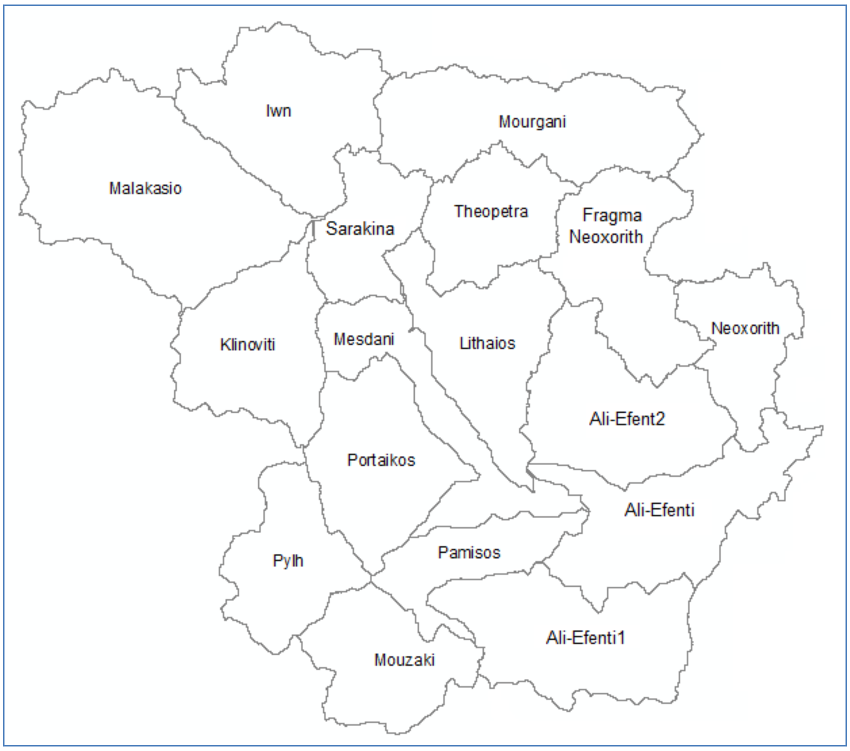


Figure 8.26: The 17 management sub-catchments of the Ali-Efenti basin used in the drought vulnerability and risk analysis

The WRMM output data of unmet demand have been used to feed the calculation of the three DVI sub-indicators applied across all sectors (domestic, agriculture, livestock, industry) as follows:

REL: percent (%) of years with unmet demand within the period of analysis. This sub-indicator is used as metrics of "water supply reliability".

DIS: Average unmet demand within the period of analysis as percentage (%) of the respective total demand. This sub-indicator is used as metrics of “distance to target”.

EXT: Maximum annual unmet demand within the period of analysis as percentage (%) of the respective total demand of that same year. This sub-indicator is used as metrics of “resilience to extreme conditions”.

On the basis of the results, each sub-catchment has been classified into a class (1 being a low, to 4 being a very high vulnerability class) for each sub-indicator, following the classification proposed in Chapter 4 (Table 8.19). The values and score for each sub-indicator are provided per catchment in the Table 8.20 to Table 8.22 below.

Table 8.19: Classification of the REL, DIS and EXT sub-indicators

REL **% of years with unmet demand**	**DIS** **Average Unmet demand as % of Total demand**	**EXT** **Maximum annual unmet demand as % the total demand of that year**	**Score/ Class**
0-9%	0-9%	0-9%	1 - low
10-19%	10-19%	10-19%	2 – moderate
20-29%	20-29%	20-29%	3 – high
>30%	>30%	>30%	4 – very high

Table 8.20: Results and classes for the REL sub-indicator for each sub-catchment

	1981-2010			1981-1995			1996-2010			
SUB-CATCHMENT	# of years with UNMET demand	% of years with unmet demand (at least one node in the catchment)	Class	# of years with UNMET demand	% of years with unmet demand (at least one node in the catchment)	Class	# of years with UNMET demand	% of years with unmet demand (at least one node in the catchment)	Class	% change from 1981-1995 to 1996-2010
Ali - Efenti1	7	23%	3	2	13%	2	5	33%	4	20%
Ali - Efenti2	7	23%	3	2	13%	2	5	33%	4	20%
Ali-Efenti	30	100%	4	15	100%	4	15	100%	4	0%
Fragma Neoxoriti	0	0%	1	0	0%	1	0	0%	1	0%
Ion	0	0%	1	0	0%	1	0	0%	1	0%
Klinovitis	0	0%	1	0	0%	1	0	0%	1	0%
Lithaios	23	77%	4	12	80%	4	11	73%	4	-7%
Malakasio	0	0%	1	0	0%	1	0	0%	1	0%
Mesdani	7	23%	3	2	13%	2	5	33%	4	20%
Mourgani	0	0%	1	0	0%	1	0	0%	1	0%
Mouzaki	0	0%	1	0	0%	1	0	0%	1	0%
Neoxoritis	24	80%	4	12	80%	4	12	80%	4	0%
Pamisos	7	23%	3	2	13%	1	5	33%	4	20%
Pili	27	90%	4	14	93%	4	13	87%	4	-7%
Portaikos	0	0%	1	0	0%	1	0	0%	1	0%
Sarakina	0	0%	1	0	0%	1	0	0%	1	0%
Theopetra	26	87%	4	12	80%	4	14	93%	4	13%
									average change	*5%*

Table 8.21: Results and classes for the DIS sub-indicator for each sub-catchment

	1981-2010			1981-1995			1996-2010			
SUB-CATCHMENT	Average UNMET demand	Unmet demand as % of the Total Demand of the catchment	Class	Average UNMET demand	Unmet demand as % of the Total Demand of the catchment	Class	Average UNMET demand	Unmet demand as % of the Total Demand of the catchment	Class	% change from 1981-1995 to 1996-2010
Ali - Efenti1	3,85	3%	1	0,81	1%	1	6,89	6%	1	5%
Ali - Efenti2	2,22	2%	1	0,43	0%	1	4,00	4%	1	4%
Ali-Efenti	14,70	19%	2	13,61	17%	2	15,79	20%	3	3%
Fragma Neoxoriti	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Ion	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Klinovitis	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Lithaios	0,69	2%	1	0,43	1%	1	0,96	3%	1	2%
Malakasio	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Mesdani	2,23	4%	1	0,46	1%	1	4,00	6%	1	6%
Mourgani	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Mouzaki	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Neoxoritis	1,42	11%	2	1,54	12%	2	1,30	10%	2	-2%
Pamisos	0,02	0%	1	0,01	0%	1	0,04	0%	1	0%
Pili	1,22	2%	1	0,66	1%	1	1,78	3%	1	2%
Portaikos	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Sarakina	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Theopetra	0,26	11%	2	0,23	10%	2	0,29	12%	2	2%
									average change	***1%***

Table 8.22: Results and classes for the EXT sub-indicator for each sub-catchment

SUB-CATCHMENT	1981-2010 UNMET demand (2007)	1981-2010 Unmet demand as % of the Total Demand of the catchment	1981-2010 Class	1981-1995 UNMET demand (1990)	1981-1995 Unmet demand as % of the Total Demand of the catchment	1981-1995 Class	1996-2010 UNMET demand (2007)	1996-2010 Unmet demand as % of the Total Demand of the catchment	1996-2010 Class	% change from 1981-1995 to 1996-2010
Ali - Efenti1	38,09	31%	4	10,23	9%	1	38,09	31%	4	23%
Ali - Efenti2	22,20	22%	3	5,24	5%	1	22,20	22%	3	16%
Ali-Efenti	16,74	21%	3	22,98	30%	4	16,74	21%	3	-8%
Fragma Neoxoriti	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Ion	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Klinovitis	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Lithaios	4,49	14%	2	2,28	7%	1	4,49	14%	2	7%
Malakasio	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Mesdani	21,43	33%	4	6,11	10%	1	21,43	33%	4	23%
Mourgani	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Mouzaki	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Neoxoritis	2,06	16%	2	1,92	15%	2	2,06	16%	2	1%
Pamisos	0,18	2%	1	0,06	1%	1	0,18	2%	1	1%
Pili	8,48	14%	2	4,74	8%	1	8,48	14%	2	6%
Portaikos	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Sarakina	0,00	0%	1	0,00	0%	1	0,00	0%	1	0%
Theopetra	0,29	12%	2	0,36	15%	2	0,29	12%	2	-3%
									average change	***4%***

The above 3 sub-indicators calculated for each sub-catchment, have been blended into a Drought Vulnerability Index (DVI) using equal weights, using the following equation:

$$DVI = \frac{score_{REL} + score_{DIS} + score_{EXT}}{3} \qquad (4)$$

The resulting DVI values to range from 1-4 (less to more vulnerable to the drought hazard) since all the sub-indicators scores are 1-4 and their relevant weights are all equal. The following classification is proposed for the DVI values (Table 8.23) as also presented in Chapter 4. The resulting DVI values per sub-catchment are provided in the below (Table 8.24).

Table 8.23: Classification of the Drought Vulnerability Index (DVI)

DVI value	Vulnerability class
1.00 – 1.49	1 – low
1.50 – 2.49	2 – moderate
2.50– 3.49	3 – high
3.49 – 4.00	4 – very high

Table 8.24: Results and classes of the Drought Vulnerability Index (DVI) for each sub-catchment

Sub-catchments	DVI (1981-2010)	DVI (1981-1995)	DVI (1996-2010)	Change in DVI from 1981-1995 to 1996-2010
Ali - Efenti	2,67	1,33	3,00	1,67
Ali - Efenti1	2,33	1,33	2,67	1,33
Ali-Efenti2	3,00	3,33	3,33	0,00
Fragma Neoxoriti	1,00	1,00	1,00	0,00
Ion	1,00	1,00	1,00	0,00
Klinovitis	1,00	1,00	1,00	0,00
Lithaios	2,33	2,00	2,33	0,33
Malakasio	1,00	1,00	1,00	0,00
Mesdani	2,67	1,33	3,00	1,67
Mourgani	1,00	1,00	1,00	0,00
Mouzaki	1,00	1,00	1,00	0,00
Neoxoritis	2,67	2,67	2,67	0,00

Pamisos	1,67	1,00	2,00	1,00
Pili	2,33	2,00	2,33	0,33
Portaikos	1,00	1,00	1,00	0,00
Sarakina	1,00	1,00	1,00	0,00
Theopetra	2,67	2,67	2,67	0,00

Out of the 17 sub-catchments, 5 are classified in class 3 (high vulnerability), 4 in class 2 (moderate), and the reaming 8 are in class 1 (low vulnerability) when analyzing the entire period 1981-2010. Looking at the two sub-periods individually (1981-1995 and 1996-2010) we can observe an overall increase in vulnerability across the catchments. During the 1981-1995 3 catchments were falling under class 3, while this number has doubled in the period 1996-2010 (6 catchments in class 3). Overall, the average increase in vulnerability across the two sub-periods is around 0.37 which basically represents 37% of a class span, in other words an average increase of about 1/3rd of a class is observed. The Ali-Efenti, Ali-Efenti1 and the Mesdani sub-catchments demonstrate the largest increase in vulnerability across the years; from class 1 originally in the 1981-1995 they are now in class 3 regarding the 1996-2010 period (increase of 2 classes).

Maps of the resulting DVI for the entire 1981-2010 period, as well at the sub-periods 1981-1995 and 1995-2010 (to allow for comparison), as well as a map reflecting the change between the 2 sub-periods are provided below (Figure 8.27 and Figure 8.28). It is observed that the south-eastern part of the Ali-Efenti is most vulnerable (medium to high degree of vulnerability) to drought during the period 1981-2010, with Ali-Efenti 1, Ali-Efenti 2, Neoxoritis, and Mesdani being the most vulnerable (class 3). Theopetra sub-catchment in the north-eastern also experiences a high degree of vulnerability. Looking at the 2 individual sub-periods, an increase in the vulnerability is observed during the 1996-2010: some sub-basins previously classified in class 1 (low vulnerability) demonstrate now moderate (Pamisos) or high vulnerability conditions (Mesdani, Ali-Efenti 1, Ali-Efenti). The greater increase in vulnerability, more than 1.5 change in the DVI value, is observed in the sub-catchments of Mesdani and Ali-Efenti, where main irrigated areas are located.

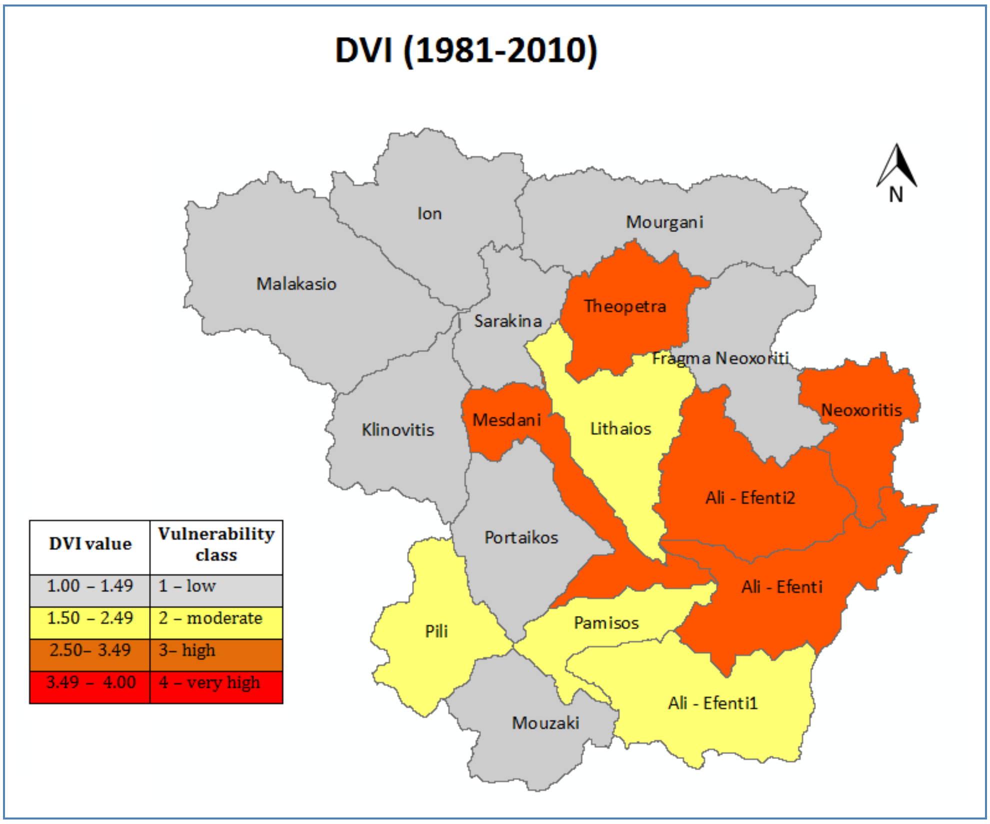
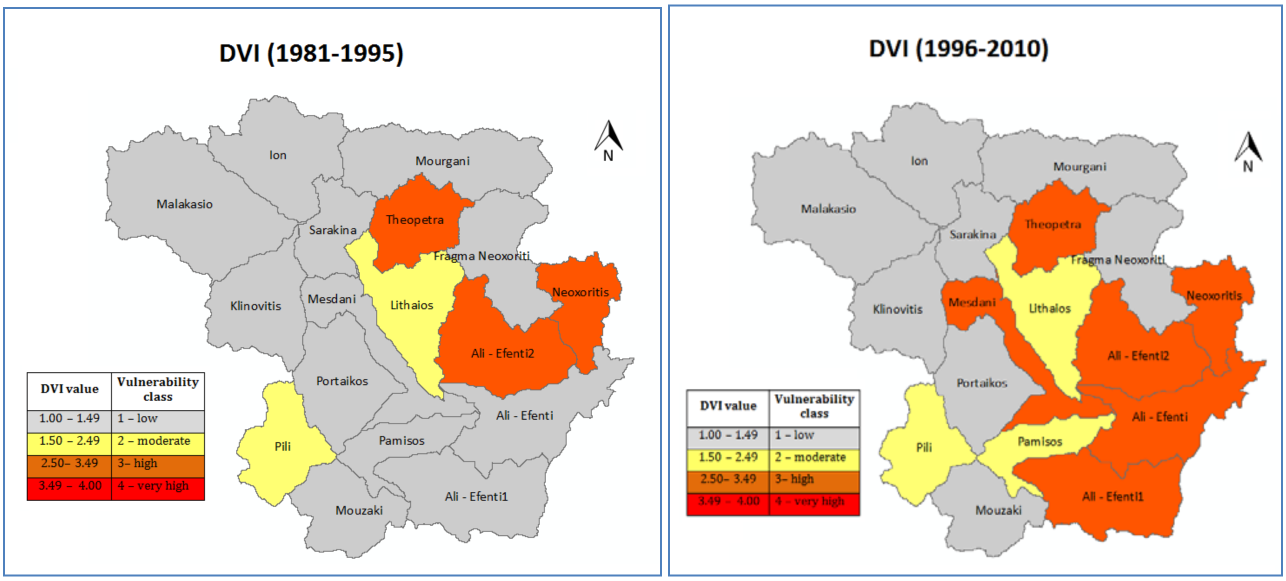
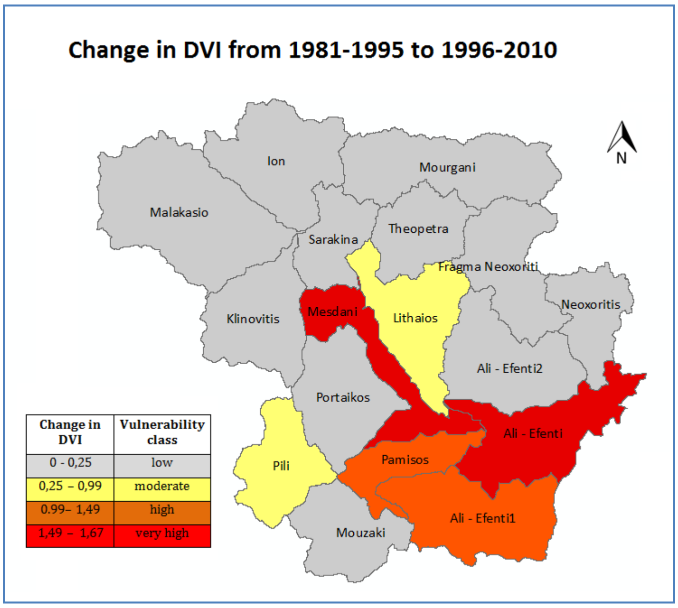


Figure 8.27: The DVI in the Ali-Efenti sub-catchments from the period 1981-2010



(a) (b)



(c)

Figure 8.28: The DVI in the Ali-Efenti sub-catchments: (a) for the sub-period 1981-1995, (b) for the sub-period 1996-2010, (c) change across the 2 sub-periods.

The final step in deriving the Drought Risk Profile (DRP) of the Ali-Efenti involves the calculation of the Drought Risk Index (DRI) by multiplying the DHI and DVI. As the spatial resolution of the indicators is not identical (DHI is calculated at grid level, DVI is calculated at the sub-catchment level), GIS geoprocessing has been performed to convert DVI vector shapefiles to raster, to allow for the subsequent grid-based calculation of the DRI. The resulting DRI maps for the entire 1981-2010 period, as well at the sub-periods 1981-1995 and 1995-2010 (to allow for comparison), as well as map reflecting the change between the 2 sub-periods are provided below in Figure 8.29 and Figure 8.30. Overall, for the period 1981-2010 moderate drought risk (DHI= 2.10-5.00) is observed in the northern part of the Ali-Efenti and in some parts of the central area of the basin. High risk is observed in the south-eastern part of the Ali-Efenti, with the sub-catchments of Lithaios, Mesdani, Neoxoritis, Ali-Efenti, Ali-Efenti 1, and Ali-Efenti 2 being exposed. Pyli (in the south-western) also experiences a moderate drought risk. In the very center, a small area of the Ali-Efenti demonstrates a very high risk. If we zoon into the two sub-periods, we can observe a shift of the risk areas towards the southern part of the basin: the northern part of the basin is becoming less prone to drought (risk classes decline from moderate to low), while the south-eastern part becomes more prone (risk classes increase from low to high). The highest increases in the DRI (change > 5) are observed in the Mesdani, Ali-Efenti and Ali-Efenti sub-catchments, where the main irrigated areas are located.

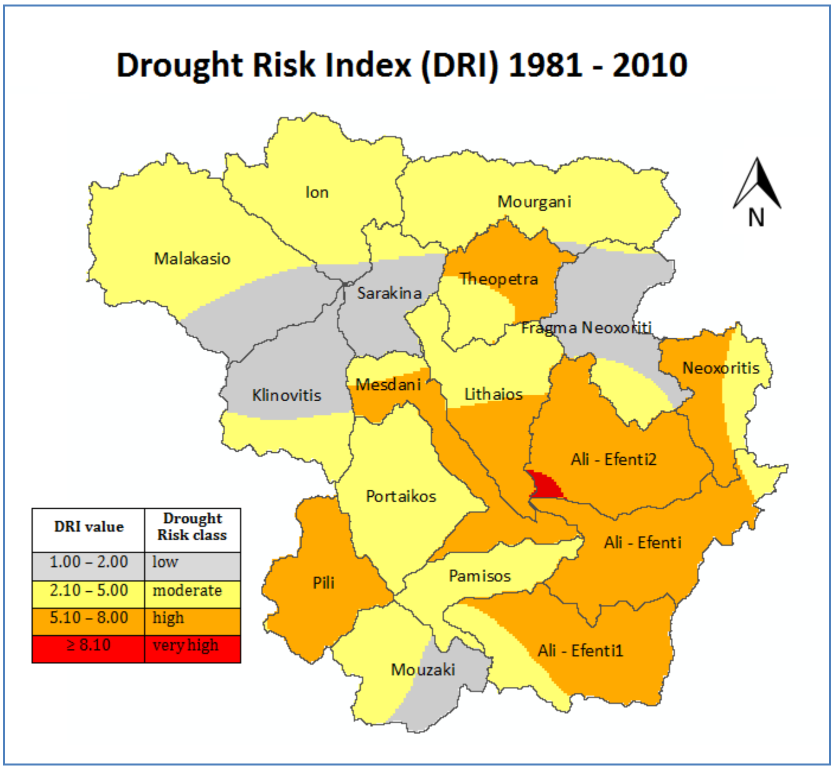
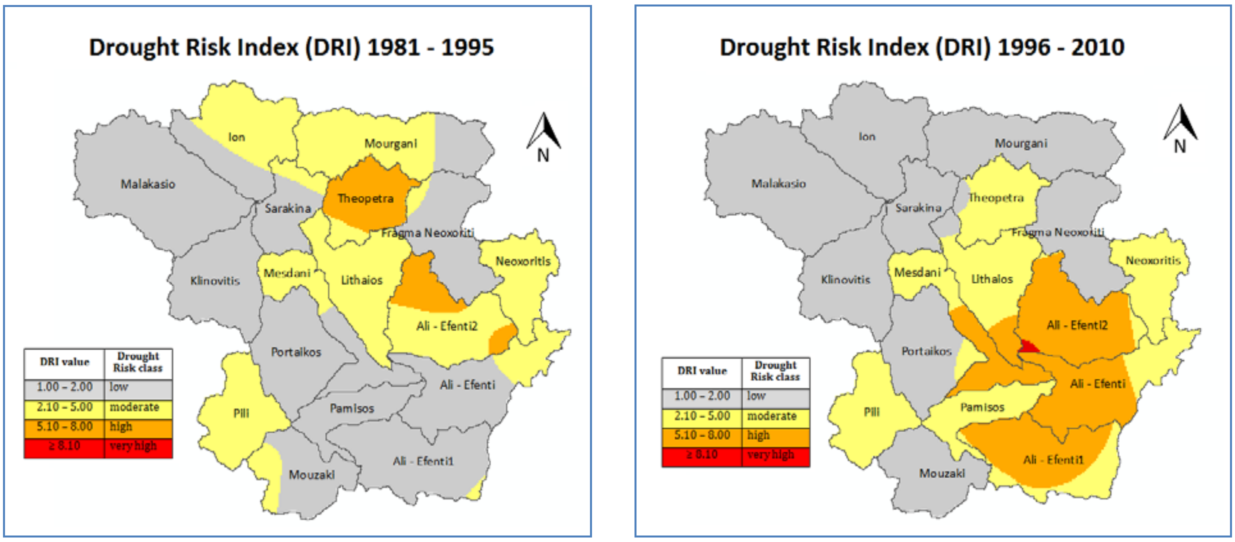
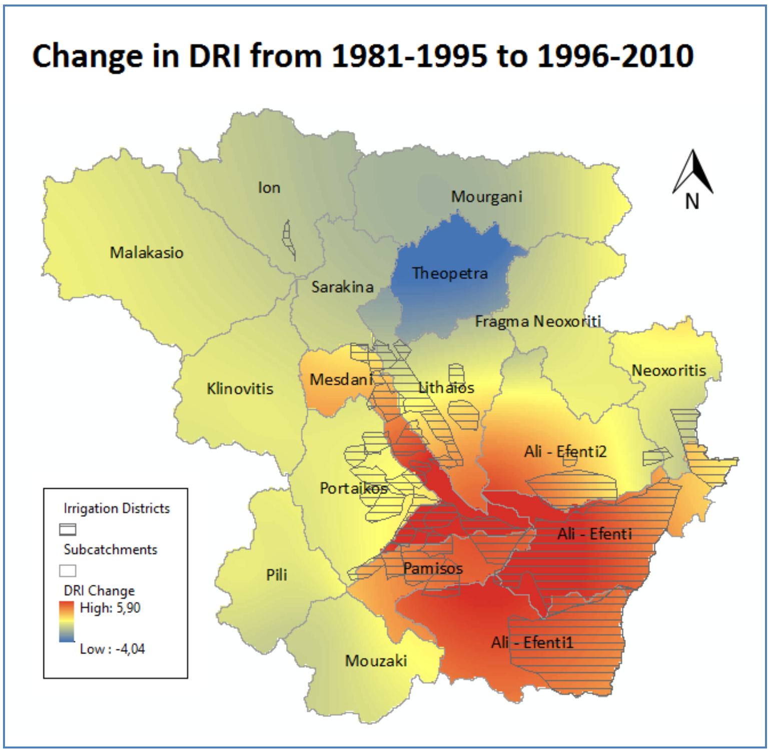


Figure 8.29: The DRI in the Ali-Efenti sub-catchments from the period 1981-2010



(a) (b)



(c)

Figure 8.30: The DRI in the Ali-Efenti sub-catchments: (a) for the sub-period 1981-1995, (b) for the sub-period 1996-2010, (c) change across the 2 sub-periods.

8.6 Simulation and assessment of adaptation options for the Ali-Efenti basin

The interventions curves (developed based on the methodology of Chapter 5) have been implemented within the WEAP Water Resources Management Model of the Ali-Efenti in order to further assess their effectiveness against this physical based model. In order to simulate them in WEAP new user-defined parameters have been introduced in the model. The resulting water savings, when applying the measures, have been evaluated for the year 2007 (the most dry year with the maximum unmet demand) across the various demand sites (urban and agriculture nodes) of the model.

8.6.1 Simulation and assessment of the urban demand management measures in WEAP

In order to implement the urban intervention curve developed in the previous Chapter 5 into the WEAP WRMM of the Ali-Efenti, a user-defined variable "Water saving measures Coefficient (Wmu)" was introduced in the model. Wmu represents the percentage of water saved by applying the bundle of urban water saving measures of the intervention curve. In order to calculate the final water demand after the application of the measures, WEAP multiplies the daily water use per capita with (1-Wmu).

As discussed in Chapter 5, a total of 7 water saving measures have been considered: istallation of dual flush toilets (1), retrofitting of low flow taps (2) and showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. The Ali-Efenti basin has a population of 190,276 people, and considering an average household size of 2.8 persons a total of 67,956 households are estimated in the area. Tier 1 measures comprise of dual flash toilets, low flow taps and showerheads, efficient washing machines and dishwashers, while tier 2 measures additionally include rainwater harvesting and domestic greywater reuse systems. As estimated in Chapter 5 (Table 5.7), the total potential water saving, if applying all tier 1 measures (i.e. creating a "water efficient house"), is estimated to reach 46.5% of the total household consumption. The application of additional tier 2 measures (rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier 1 measures in a "water efficient" house delivers an additional 16.2% saving, thus a total of 62.7% domestic water saving potential.

In our simulation the daily water use per capita was set to 170 l/cap/day, so in the case of applying all available measures to all the households the demand would drop to (1-0.627)*170 = 63.4 l/cap/day. In this case a surplus of 12 mio m³ water is generated after covering all urban demands, since the demand is now much less than the potential available urban water supply. This surplus can be allocated to the agricultural water use. More realistic solutions, based on expert judgment, are in the range of 20-45% savings, which result in a daily water use rate of 136-94 lt/cap.

Different selected solutions of the urban intervention curve (from Table 5.8 of Chapter 5) have been simulated in the model, as summarized in Table 8.25. The full list of solution can be found in Annex 3. The results of the simulation of these solutions are presented in Table 8.26 while the cumulative water savings (moving from the low cost to the highest cost solutions) per urban demand node are depicted in Figure 8.31.

Table 8.25: Selected solutions of the urban cost-effective intervention curve that have been simulated in the Ali-Efenti WRMM

Water Saving %	AEC per HH €	Total water saving * (mio m³)	Total AEC mio €	€/m³ of water saved	*Penetration (% of the households adapting the measure)*						
					Dual flush toilet	*Shower-heads (1 item)*	*Low flow taps (2 items)*	*Efficient Washing Machine*	*Dish-washer*	*RWH*	*GWR*
7.7 %	4 €	1.49	0.29 €	0.20	0	38%	0	0	0	0	0
20.4 %	15 €	3.93	1.00 €	0.26	13%	94%	0	0	0	0	0
34.0 %	53 €	6.46	3.62 €	0.56	91%	100%	70%	0	0	0	0
43.1 %	199 €	8.32	13.56 €	1.63**	100%	100%	100%	89%	0%	9%	0
49.6 %	397 €	9.56	26.97 €	2.82	100%	100%	100%	89%	9%	63%	0
62.7 %	1,158 €	12.11	78.73 €	6.50	100%	100%	100%	100%	100%	100%	100%

* The total water saving is based on the supply delivered in the Ali-Efenti case study in the dry year 2007 (which equals 19.29 mio m³), and has been calculated by applying the % saving on that value, in order to allow for some subsequent estimation of cost-benefit. Based on the study area and application this value is adjusted by the user.

** This value falls within the lower and upper bounds of the current total cost of water in the Ali-Efenti pilot area. This cost includes the financial, environmental and resource cost as estimated in the WFD River Basin Management Plan of the Thessaly RBD (YPEKA EGY, 2011).

Table 8.26: Model results of the simulated selected solutions in the urban sector

Urban Demand Node	2007 Baseline Conditions			Simulation with Wmu = 7.7%			Simulation with Wmu = 20.4%			Simulation with Wmu = 34%		
	Water Demand (mio m³)	Supply Delivered (mio m³)	Unmet Demand (mio m³)	Water Saving (mio m³)	New Water Demand (mio m³)	Water Surplus (mio m³)	Water Saving (mio m³)	New Water Demand (mio m³)	Water Surplus (mio m³)	Water Saving (mio m³)	New Water Demand (mio m³)	Water Surplus (mio m³)
Vassiliki	0.56	0.56	0.00	0.12	0.45	0.12	0.04	0.52	0.04	0.19	0.37	0.19
Gomfoi	0.51	0.51	0.00	0.10	0.40	0.10	0.04	0.47	0.04	0.17	0.33	0.17
Kalambaka	1.17	1.17	0.00	0.24	0.93	0.24	0.09	1.08	0.09	0.40	0.78	0.40
Karditsa	4.19	4.19	0.00	0.85	3.33	0.85	0.32	3.87	0.32	1.42	2.77	1.42
Koziakas	0.26	0.26	0.00	0.05	0.21	0.05	0.02	0.24	0.02	0.09	0.17	0.09
Malakasio	0.41	0.41	0.00	0.08	0.33	0.08	0.03	0.38	0.03	0.14	0.27	0.14
Kalyvia	0.31	0.31	0.00	0.06	0.25	0.06	0.02	0.29	0.02	0.11	0.21	0.11
Mouzaki	0.97	0.97	0.00	0.20	0.77	0.20	0.07	0.90	0.07	0.33	0.64	0.33
Oixalia	0.56	0.56	0.00	0.12	0.45	0.12	0.04	0.52	0.04	0.19	0.37	0.19
Ithomi	0.75	0.75	0.00	0.15	0.59	0.15	0.06	0.69	0.06	0.25	0.49	0.25
Pelinaioi	0.90	0.90	0.00	0.18	0.72	0.18	0.07	0.83	0.07	0.31	0.60	0.31
Pialeia	0.36	0.36	0.00	0.07	0.29	0.07	0.03	0.34	0.03	0.12	0.24	0.12
Pyndaoi	0.14	0.14	0.00	0.03	0.11	0.03	0.01	0.13	0.01	0.05	0.09	0.05
Pyli	0.42	0.42	0.00	0.08	0.33	0.08	0.03	0.38	0.03	0.14	0.27	0.14
Sellana	0.52	0.52	0.00	0.11	0.41	0.11	0.04	0.48	0.04	0.18	0.34	0.18
Trikala	5.99	5.63	0.36	1.22	4.77	0.86	0.46	5.53	0.10	2.04	3.96	1.68
Tymfaoi	0.16	0.16	0.00	0.03	0.13	0.03	0.01	0.15	0.01	0.05	0.10	0.05
Faloria	0.65	0.65	0.00	0.13	0.52	0.13	0.05	0.60	0.05	0.22	0.43	0.22
Farkadona	0.47	0.47	0.00	0.10	0.38	0.10	0.04	0.44	0.04	0.16	0.31	0.16
Chassioi	0.33	0.33	0.00	0.07	0.26	0.07	0.03	0.30	0.03	0.11	0.22	0.11
Total Volume	19.65	19.29	0.36	4.01	15.64	3.65	1.51	18.14	1.15	6.68	12.97	6.32
AEC (mio €)				1.00 €			0.29 €			3.62 €		
€/m³ saved				0.25			0.19			0.54		

Urban Demand Node	Simulation with Wmu = 34%			Simulation with Wmu = 43.1%			Simulation with Wmu = 49.6%			Simulation with Wmu = 62.7%		
	Water Saving (mio m^3)	New Water Demand (mio m^3)	Water Surplus (mio m^3)	Water Saving (mio m^3)	New Water Demand (mio m^3)	Water Surplus (mio m^3)	Water Saving (mio m^3)	New Water Demand (mio m^3)	Water Surplus (mio m^3)	Water Saving (mio m^3)	New Water Demand (mio m^3)	Water Surplus (mio m^3)
Vassiliki	0.19	0.37	0.19	0.28	0.28	0.28	0.24	0.32	0.24	0.35	0.21	0.35
Gomfoi	0.17	0.33	0.17	0.25	0.26	0.25	0.22	0.29	0.22	0.32	0.19	0.32
Kalambaka	0.40	0.78	0.40	0.58	0.59	0.58	0.51	0.67	0.51	0.74	0.44	0.74
Karditsa	1.42	2.77	1.42	2.08	2.11	2.08	1.81	2.38	1.81	2.63	1.56	2.63
Koziakas	0.09	0.17	0.09	0.13	0.13	0.13	0.11	0.15	0.11	0.16	0.10	0.16
Malakasio	0.14	0.27	0.14	0.21	0.21	0.21	0.18	0.24	0.18	0.26	0.15	0.26
Kalyvia	0.11	0.21	0.11	0.16	0.16	0.16	0.13	0.18	0.13	0.20	0.12	0.20
Mouzaki	0.33	0.64	0.33	0.48	0.49	0.48	0.42	0.55	0.42	0.61	0.36	0.61
Oixalia	0.19	0.37	0.19	0.28	0.28	0.28	0.24	0.32	0.24	0.35	0.21	0.35
Ithomi	0.25	0.49	0.25	0.37	0.38	0.37	0.32	0.43	0.32	0.47	0.28	0.47
Pelinaioi	0.31	0.60	0.31	0.45	0.46	0.45	0.39	0.51	0.39	0.57	0.34	0.57
Pialeia	0.12	0.24	0.12	0.18	0.18	0.18	0.16	0.21	0.16	0.23	0.14	0.23
Pyndaoi	0.05	0.09	0.05	0.07	0.07	0.07	0.06	0.08	0.06	0.09	0.05	0.09
Pyli	0.14	0.27	0.14	0.21	0.21	0.21	0.18	0.24	0.18	0.26	0.16	0.26
Sellana	0.18	0.34	0.18	0.26	0.26	0.26	0.22	0.29	0.22	0.32	0.19	0.32
Trikala	2.04	3.96	1.68	2.97	3.02	2.61	2.58	3.41	2.22	3.76	2.24	3.40
Tymfaoi	0.05	0.10	0.05	0.08	0.08	0.08	0.07	0.09	0.07	0.10	0.06	0.10
Faloria	0.22	0.43	0.22	0.32	0.33	0.32	0.28	0.37	0.28	0.41	0.24	0.41
Farkadona	0.16	0.31	0.16	0.24	0.24	0.24	0.20	0.27	0.20	0.30	0.18	0.30
Chassioi	0.11	0.22	0.11	0.16	0.17	0.16	0.14	0.19	0.14	0.21	0.12	0.21
Total Volume	6.68	12.97	6.32	9.75	9.90	9.38	8.47	11.18	8.11	12.32	7.33	11.96
AEC (mio €)	3.62 €			13.56 €			26.95 €			78.73 €		
€/m^3 saved	0.54			1.39			3.18			6.39		

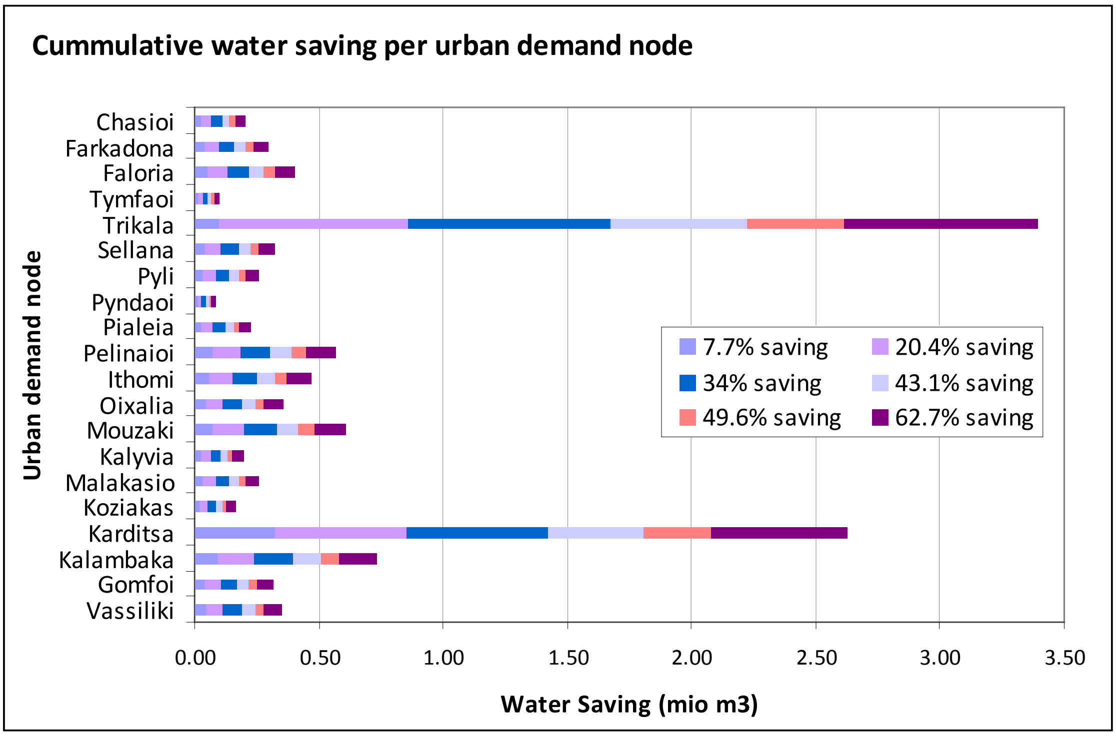


Figure 8.31: Overview of the cumulative water savings (moving from the low cost to the highest cost solutions) per urban demand node

The results of the model simulation depict the variability in water savings among the different demand nodes. The Business as Usual (BaU) represents the current situation, thus no measures are adopted, water saving is 0%, and the unmet demand remains at current levels (0.36 mio m^3 for the dry year 2007). With a very low cost of less than 5 € AEC (specifically 4.3 €/household) a rough 8% saving of the urban water use can be achieved. This solution requires the installation of low-flow showerheads in 38% of the households in the Ali-Efenti. About 20% saving can be achieved with an AEC of 15 €/hh and requires the installation of dual flush toilets in 13% of the households and low-flow showerheads in 94% of the households in the area. The total AEC in this case reaches 1 million € with a total water saving of 4.01 mio m^3, thus 0.25 €/m^3 of water saved. Respectively, with a cost of 0.54 €/m^3 of water saved (or AEC 53 €/hh) 34% of water can be saved (i.e. 6.68 mio m^3 in total). The latter requires the quasi-full penetration of low-flow showerheads and dual flush toilets (91%), and further introduces low-flow taps (2 items per hh) in 70% of the households. To further save water beyond the level of 37% additional tier 1 measures (on top of the dual flush toilets, low-flow showerheads and taps) are gradually required, i.e. efficient washing machines followed by dishwashers, starting for a degree of penetration of 9% and gradually increasing. Two interesting solutions are observed at the range of 43% water saving, with an AEC of about 200 €/hh. These solutions require a unit cost of about 1.4 €/m^3 which is close to the average cost of water in the area. In this case RWH systems are introduced in 9% of the households while the penetration of dishwashers is restricted to either 0% or 16%. Above the level of 45.5% saving the unit cost of water saved is more than 2.1 €/m^3 and thus relatively expensive. To reach a 50% water saving (i.e. total of 8.47 mio m^3 water saved) the AEC per household reaches 397 € while the total investment sums up to 27 mio €. In this case RWH has penetrated in 63% of the households. Greywater reuse systems are firstly introduced when all other measures have penetrated in all households, at a level of 6% securing 58% saving with an AEC of 683 €/hh. Their degree of penetration gradually increases, with a subsequent increase in water savings and costs, up to full penetration with 62.7% saving and AEC 1,158 €/hh. This represents the maximum water saving potential of 12.32 mio m^3, with a total investment cost of 78.7 mio € per year, and a unit cost of 6.36 €/m^3 of water saved.

As discussed, beyond the level of 37% saving target, the equivalent unit cost in €/m^3 of water saved fluctuates within the boundaries of the total cost of water in the areas, and eventually exceeds it (Table 8.27). The total cost of water has been estimated in the WFD River Basin Management Plan of the Thessaly RBD (YPEKA EGY, 2011) and includes the financial, environmental and resource cost (Table 8.27). As it can be observed it ranges among the Municipal Enterprises of Water Supply and Sewerage (DEYA) in the area from 0.68 €/m^3 up to 2.086 €/m^3, with an average cost of 1.76 €/m^3. They higher cost is associated with the larger DEYAs' such as the ones of Trikala and Karditsa. It worth's noticing that the current cost recovery ranges from 69.5 – 135% (average 89.4 %) when the special taxes are included, while it is lower (53 -73%, average 63%) when special taxes are excluded (Table 8.27). With regard to urban water pricing (volumetric increasing block-tariffs IBT) this also varies among the DEYA, with 0.15-1.20 €/m^3 at the low consumption levels, and 0.27-2.27 €/m^3 at the higher consumption levels (the higher level tariffs apply when more than 61-401 m^3 are consumed per trimester). Thus, it is obvious that after some point the urban measures become too expensive (beyond the 45% water saving target), more than the actual cost of water.

Table 8.27: Cost of water in various Municipal Enterprises of Water Supply and Sewerage (DEYA) of the Thessaly RBD

DEYA	Financial Cost €	Environmental Cost €	Resource Cost €	Total Cost €	% Cost recovery (including	% Cost recovery (excluding

					special taxes)	special taxes)
DEYA Karditsa	2.024 €	0.017 €	0 €	2.041 €	75.6 %	53.0 %
DEYA Kalambaka	1.498 €	0 €	0 €	1.498 €	87.6 %	61.1 %
DEYA Trikala	2.086 €	0 €	0 €	2.086 €	84.4 %	56.3 %
DEYA Mouzaki	0.680 €	0 €	0 €	0.680 €	69.5 %	n/a
DEYA Farkadona	0.869 €	0 €	0 €	0.869 €	134.7 %	72.9 %
DEYA Palama	1.737 €	0 €	0.035 €	1.772 €	89.4 %	63.1 %
AVERAGE *across all DEYA in Thesaly RBD*	**1.737 €**	**0.005 €**	**0.018 €**	**1.760 €**	**89.4 %**	**63.1 %**

* The financial cost refers to the year 2008 but is adjusted to 2010 prices. The environmental and resource costs refer to the year 2010. Source: YPEKA EGY, 2011.

Trikala and Karditsa have the largest water saving potential (in terms of absolute volume of urban water saved), accounting together for 52% of the total in the basin, and this is due to the fact that they represent the largest urban water consumers in the Ali-Efenti area, with the larger number of connections and users. Thus, since savings correlate with the demand and the population, it is expected that those two nodes will have greater water saving potential. The nodes of Kalambaka, Mouzaki and Pelinaioi have medium-range water saving potential (each one accounting for 5-6% of the total saving in the basin), while all other nodes have small-range water saving potential. Thus, as the current cost of water also varies across the DEYA (Table 8.27), for Karditsa and Trikala which currently have high water costs at the range 2 €/m^3 it may worth pursuing more expensive measures which provide larger savings of 40-45%, while for Mouzaki, Farkadona and other low consumers which have a current cost of water around 0.8 €/m^3 the cheaper solutions, those rendering 30-35% savings, are more balanced and defendable.

The cost-effectiveness curve of the urban measures in the whole of the area, as total urban water surplus available for allocation to other uses vs. total AEC and AEC per capita is presented in Figure 8.32. Yet, to be able to make more informed decisions about the proper selection of measures and necessary degree of saving targeted by the urban sector, one needs to look at the problem jointly with irrigation needs in the area, and the respective total cost or loss of income from under-irrigation of crops due to low agricultural supply reliability. For that purpose, a global optimization, incorporating together the urban and agricultural measures' costs and benefits is applied and discussed in a following section.

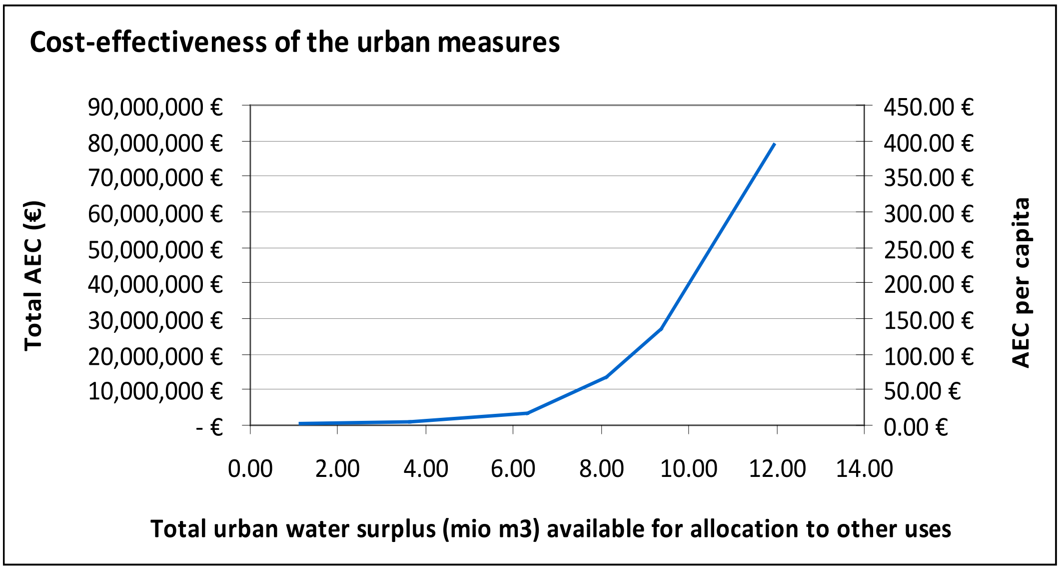


Figure 8.32: Cost-effectiveness of the urban measures with respect to the urban water surplus that can be gained for allocation to other uses

8.6.2 Simulation and assessment of the agricultural demand management measures in WEAP

According to the Water Resources Management Consortium of Central & Western Greece (2005), in 2004 the irrigated land from LORL and GOLR were 138.99 km^2 for the Trikala prefecture and 168.39 km^2 for the Karditsa prefecture. However, according to Goumas (2011), the same year the total irrigated land is estimated as approaching the 380.0 km^2 for the Trikala prefecture and 812.5 km^2 for the Karditsa prefecture, thus two to four times greater than those under the jurisdiction of LOLR/GOLR. The area of Trikala and Karditsa prefectures included in the Ali-Efenti basin are 276 km^2 and 204 km^2 respectively. For the irrigation of land outside the jurisdiction of LOLR/GOLR thousands of private boreholes are used and their number and operation can roughly be estimated.

For each Prefecture (Trikala and Karditsa) an optimum cost-effective curve is designed, as discussed in Chapter 5. The cost-effective curve for irrigation investigates and tries to find the optimum trade-off between various conveyance and irrigation methods. In other words, the investigation focuses on how much the efficiency would be improved in the prefecture if a different "mix" of conveyance and irrigation methods are used, and which ones can potentially deliver the highest efficiency with the minimum cost. Both Karditsa and Trikala Prefectures use various conveyance methods and irrigation techniques. As discussed previously Karditsa's combined efficiency in the current baseline situation is estimated to be 75.4% and Trikala's combined efficiency is 77.6%.

Similarly to the urban intervention curve design, a model in MATLAB was developed and optimized in order to create the agriculture cost-effective intervention curves for both prefectures. The percentages that represent collective and individual networks remain constant. Two decision variables have been used: the conveyance methods and the irrigation methods. Every transaction from one method (conveyance or irrigation) to another has different effectiveness and different cost. The transactions examined were only the ones which could improve the efficiency (i.e. the case of moving from closed pipes to open channels was not taken into account). Figure 8.33 presents a schematic representation of the different options embedded in the optimization process. The transactions from one method to one other are subject of constraints and cannot exceed their initial value. The variables named "Z_n" represent the area which will be irrigated with the specific method. Also variables Z1 and Z7 have an extra variable Z9 and Z10 respectevily which represent an area where precision irrigation (advanced- with minimum monitoring) is applied. The colored lines (purple, blue, red, green, bron and orange) represent the transactions. Note that each of them has different costs and benefits (potential increase in irrigation efficieny) as presented in Table 8.28.

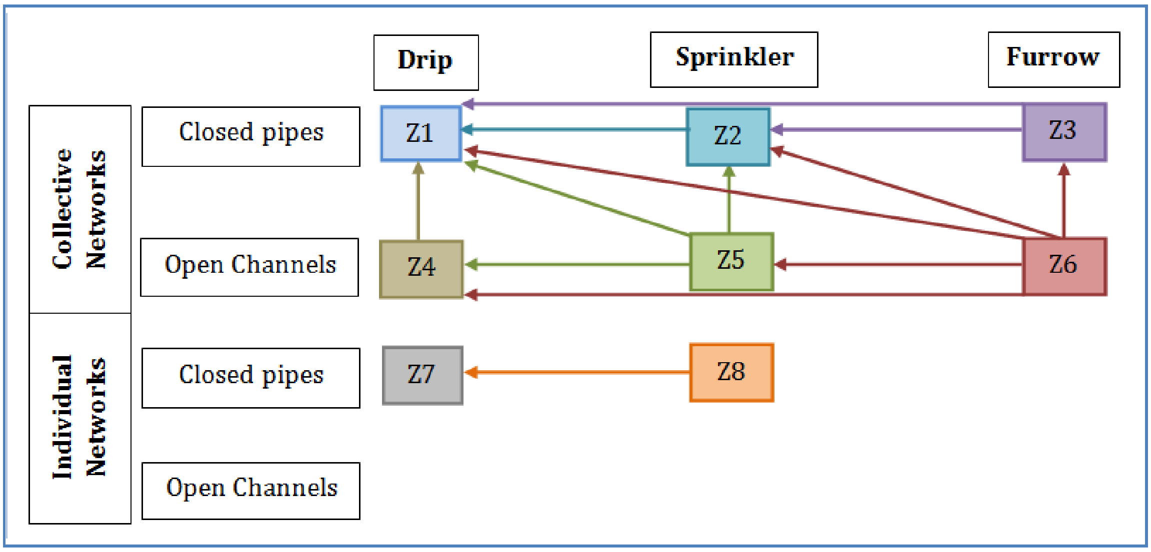


Figure 8.33: Schematic representation of the optimization process

Table 8.28: Costs and benefits of the different possible transactions simulated in the optimization process

Option	Measure	Relevant transactions	Increase in Irrigation	Cost (€/ha)

		(from Figure 8.33)	efficiency	
Increase field application efficiency	Converting from furrow irigation to sprinkler (without changing network system)	Z3 → Z2 Z6 → Z5	52% → 68% 39% → 51%	600 €/ha 600 €/ha
Increase field application efficiency	Converting from furrow or sprinkler to drip irrigation (without changing network system)	Z3 → Z1 Z6 → Z4 Z2 → Z1 Z5 → Z4 Z8 → Z7	52% → 76% 39% → 57% 68% → 76% 51% → 57% 80.8%→ 90.3%	1,200 €/ha 1,200 €/ha 1,200 €/ha 1,200 €/ha 1,200 €/ha
Increase conveyance efficiency	Converting from open chanels to closed pipes	Z6 → Z3 Z5 → Z2 Z4 → Z1	39% → 52% 51% → 68% 57% → 76%	6,000 €/ha 6,000 €/ha 6,000 €/ha
Increase both conveyance and field application efficiency	Converting from open chanels to closed pipes, and from furrow to sprinklers to drip	Z6 → Z2 Z6 → Z1 Z5 → Z1	39% → 68% 39% → 76% 51% → 76%	6,600 €/ha 7,200€/ha 7,200 €/ha
Increase field application efficiency	Apply precision agriculture	Existing drip irrigation systems → Z9 Other systems (drip irrigation modernisation is required) → Z10	+ 10% water saving from the drip irrigation water demand	134 €/ha 784 €/ha

The Matlab Global Optimization was used for the optimization process, which incorporates the NSGA-II. The total decision variables were 15, one for each transaction and two for precision irrigation. The population size was set 15*numberOfVariables=225 and the maximum generation number to 8000. Figure 8.34 and Figure 8.35 and below represent the resulting cost-effective curves for both prefectures.

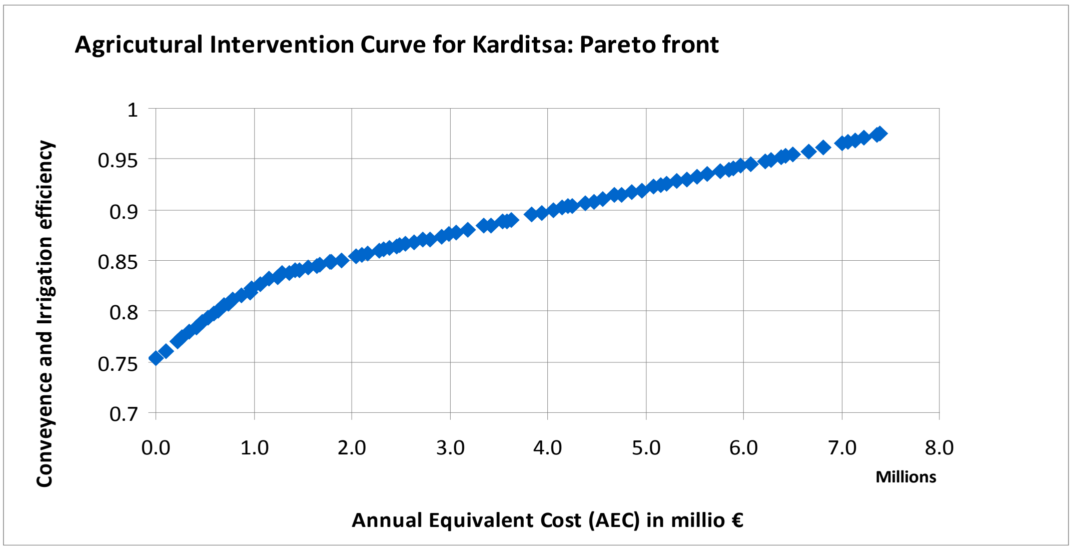


Figure 8.34: Karditsa cost-effective agricultural curve

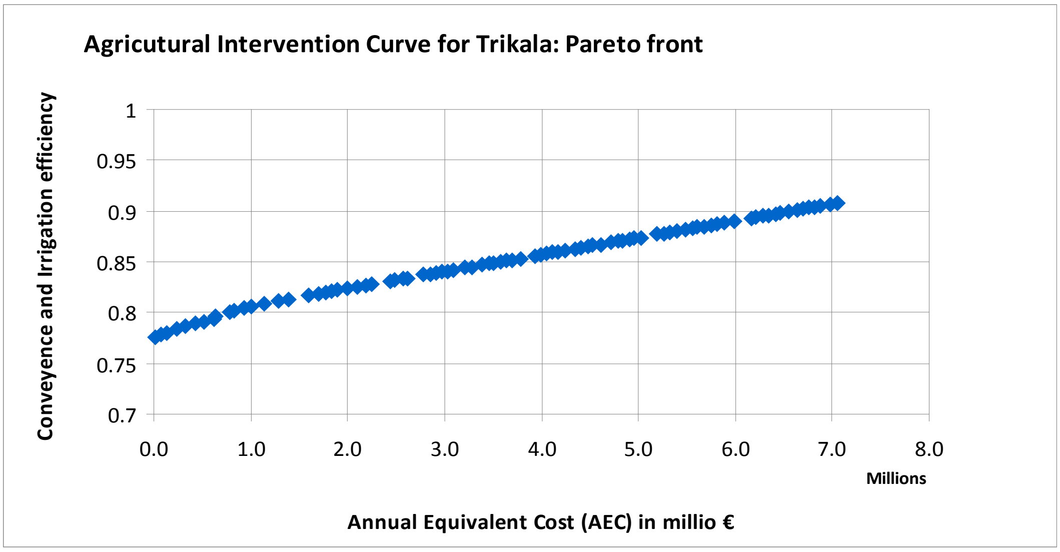


Figure 8.35: Trikala cost-effective agricultural curve

It is observed that for Karditsa (current efficiency is 0.754) increasing efficiency by 5% requires an AEC of 0.47 mio €, increasing efficiency by 10% requires an AEC of 1.06 mio €, increasing efficiency by 15% (thus reaching 0.868) requires an AEC of 2.8 mio €, while 5.97 mio € AEC are required to increase efficiency by 20%. (0.904). The maximum potential as defined by the optimization is to increase efficiency up to 0.975 (i.e. 29% increase) with an AEC of 7.39 mio €. For Trikala (current efficiency is 0.776) to increase efficiency by 5% an AEC of 1.39 mio € is required, by 10% an AEC of 3.78 mio € is required, while to reach 0.89 efficiency (i.e. 15% increase) and AEC of 6.16 mio € is required. The maximum potential as defined by the optimization is to increase efficiency up to 0.908 (i.e. 17% increase in efficiency) with an AEC of 7.06 mio €. All the above cases are associated with a bundle of changes in the networks and irrigation practices, as presented in the following Table 8.29 and Table 8.30 for Karditsa and Trikala respectively. A full list (for all solutions of the intervention curves) is presented in Annex 3. Overall, we can observe a clear correlation between the combined irrigation efficiency and the irrigation method used (sprinklers vs. drip irrigation): efficiency gains are clearly observed in both Karditsa (Figure 8.36) and Trikala (Figure 8.37) as the area irrigated with sprinklers decreases and is replaced by drip irrigation systems, while the application of precision agriculture (in the areas irrigated with drip systems) further boosts efficiency.

Table 8.29: Optimization selected solutions, and associated changes in irrigation practices, for Karditsa

			Area (ha) irrigated with Collective Networks							Area (ha) irrigated with Individual Networks		
			Closed pipes				Open channels			Closed pipes		
Efficiency	**% change in eficiency**	**Cost (AEC) (mio €)**	Furrow	Sprinkler	Drip	Drip with PA*	Furrow	Sprinkler	Drip	Sprinkler	Drip	Drip with PA*
0.754**	0%	0.00	0	600	386	0	686	2,101	515	15,970	161	0
0.793	5%	0.54	2	625	431	65	630	779	1,820	15,929	202	83
0.827	10%	1.06	1	634	847	173	197	235	2,373	15,918	213	63
0.868	15%	2.63	4	662	923	819	113	145	2,442	13,223	2,908	2,893
0.904	20%	4.25	4	662	927	820	108	144	2,443	10,003	6,128	6,085
0.943	25%	5.98	4	662	925	822	110	145	2,442	6,578	9,553	9,520
0.975	29%	7.39	4	664	929	839	105	143	2,444	3,780	12,351	12,333

* The hectares where Precision Agriculture (PA) is applied are part of the hectares under drip irrigation
** It represents the baseline current scenario in the Ali-Efenti

Table 8.30: Optimization selected solutions, and associated changes in irrigation practices, for Trikala

			Area (ha) irrigated with Collective Networks							Area (ha) irrigated with Individual Networks		
			Closed pipes				Open channels			Closed pipes		
Efficiency	**% change in eficiency**	**Cost (AEC) (mio €)**	Furrow	Sprinkler	Drip	Drip with PA*	Furrow	Sprinkler	Drip	Sprinkler	Drip	Drip with PA*
0.776**	0%	0.00	0	8,578	1,430	0	204	0	0	13,563	3,825	0

0.813	5%	1.39	6	8,452	1,729	1,465	14	8	3	12,757	4,632	4,484
0.853	10%	3.78	6	8,432	1,754	1,658	9	8	3	8,103	9,285	9,227
0.893	15%	6.16	6	8,420	1,766	1,660	9	8	3	3,375	14,013	13,955
0.908	17%	7.06	6	8,411	1,777	1,685	8	7	3	1,619	15,770	15,721

* The hectares where Precision Agriculture (PA) is applied are part of the hectares under drip irrigation
** It represents the baseline current scenario in the Ali-Efenti

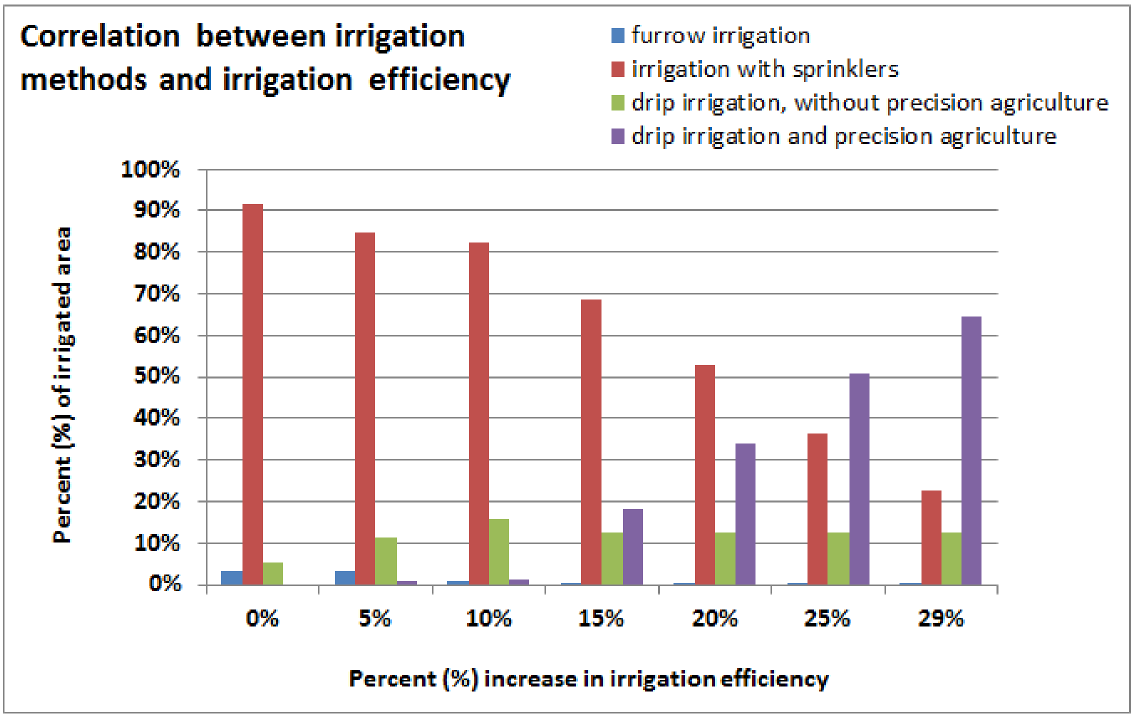


Figure 8.36: Correlation between irrigation methods and irrigation efficiency gains in Karditsa

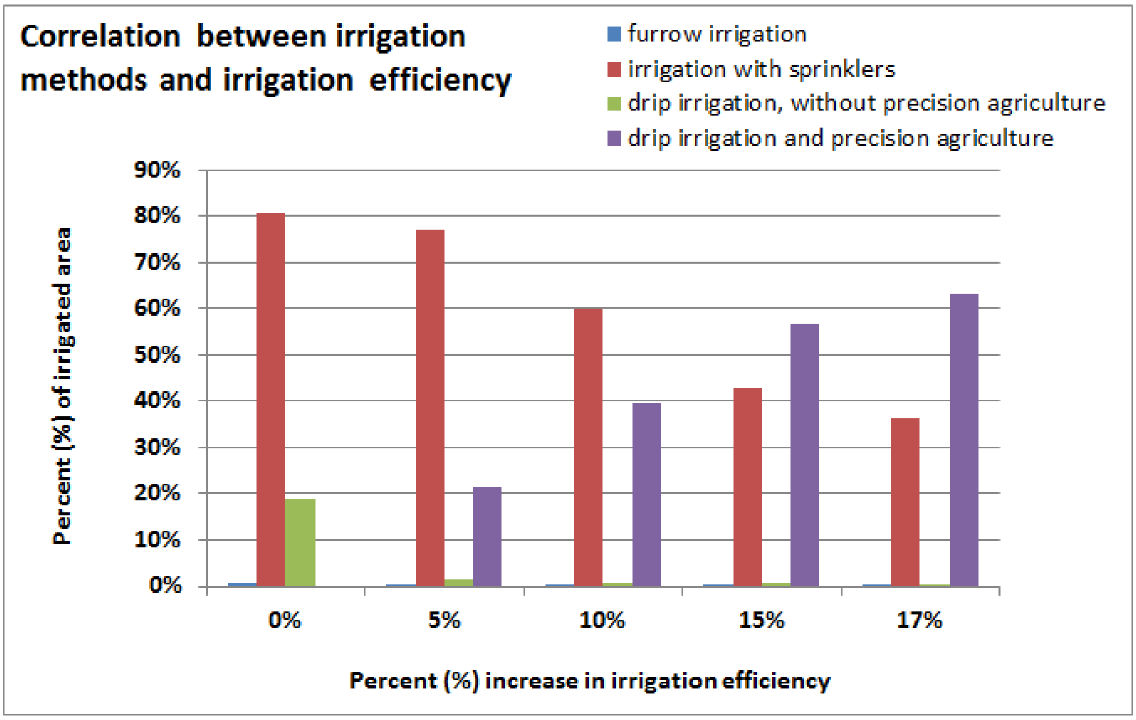


Figure 8.37: Correlation between irrigation methods and irrigation efficiency gains in Karditsa

In order to implement the agricultural intervention curve into the WEAP WRMM of the Ali-Efenti, the WEAP's key variable "Irrigation Efficiency Coefficient" was used. In our case the irrigation demand nodes (23 in total) have been divided to two large sections, falling under the prefectures of either Karditsa or Trikala. Each one of the latter a unique "Irrigation Efficiency Coefficient" variable which represents the irrigation efficiency. Efficiency gains of 5%, 10%, 15% and have been simulated by introducing the relevant efficiency coefficient values (obtained from the intervention curves) presented above, each one associated with a bundle of interventions, resulting in new values for the agricultural unmet demand. The results are presented below in Table 8.31, while the overall cost-effectiveness of the interventions (in terms of reduction achieved in the irrigation unmet demand) are presented in Figure 8.38. It is observed that approximately 20% reduction in the irrigation unmet demand can be achieved with an AEC of 4 million € (or 82 €/ha) , a 30% reduction with an AEC of 7.6 million € (or 162 €/ha), while to achieve a 50% reduction in unmet irrigation demand 10.8 million € AEC are required (or 224 €/ha). A maximum of 68% reduction can be achieved with an AEC of 14.5 million € (or 300 €/ha). Overall, we can observe that water savings accumulate incrementally as irrigation efficiency increases as a result of the applied measures (Figure 8.39). The largest incremental water saving in irrigation is achieved in the beginning, when irrigation efficiency increases by 5%, and amounts to a total of 23.3 mio m^3 for the entire basin (across all nodes). When increasing the combined efficiency by 10%, an additional 20.6 mio m^3 are saved, and another additional 20.4 mio m^3 when irrigation efficiency increases by 15%. Above that level the incremental additional water savings are less pronounced (11.4 mio m^3, 7.6 mio m^3 and 5.8 mio m^3 additional water savings when irrigation efficiency in Karditsa increases by 20%, 25% and 29% respectively). The largest savings are observed in the catchments of M.Rema2 (22 mio m^3), M. Rema1 (18 mio m^3), Pamissos-Mesdani and K. Lithaios (11 mio m^3 each), and Portaikos (8 mio m^3) (Figure 8.39). It worth noticing that in the majority of the nodes (in 74% of them) no additional savings are observed if increasing the irrigation efficiency beyond 20%.

Table 8.31: Model results of the simulated selected solutions in the agricultural sector

Agricultural Demand Node	2007 Baseline Conditions			Simulation with an irrigation efficiency increase by 5%			Simulation with an irrigation efficiency increase by 10%			Simulation with an irrigation efficiency increase by 15%		
	Water Demand (mio m^3)	Supply Delivered (mio m^3)	Unmet Demand (mio m^3)	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)
Ionas	6.31	6.31	0	6.02	6.02	0	5.74	5.74	0	5.48	5.48	0
Voula	2.84	2.84	0	2.71	2.71	0	2.58	2.58	0	2.47	2.47	0
B. Koziakas	3.18	2.66	0.52	3.03	2.55	0.48	2.89	2.44	0.45	2.76	2.33	0.43
Gavros	0.63	0.63	0	0.6	0.6	0	0.57	0.57	0	0.55	0.55	0
D. Koiti	14.48	12.5	1.98	13.82	11.86	1.96	13.17	11.25	1.92	12.58	11.59	0.99
Theopetra	2.45	2.16	0.29	2.34	2.04	0.3	2.23	1.93	0.3	2.13	1.88	0.25
K. Lithaios	73.82	57.2	16.62	70.46	53.72	16.74	67.15	50.38	16.77	64.15	51.54	12.61
Kleinovitikos	5.91	5.91	0	5.64	5.64	0	5.38	5.38	0	5.14	5.14	0
Lithaios	15.62	13.2	2.42	14.91	12.53	2.38	14.21	11.88	2.33	13.58	12.38	1.2
Loggas	0	0	0		0	0	0	0	0	0	0	0
M. Rema1	82.45	55.38	27.07	78.34	55.09	23.25	75.07	54.92	20.15	71.54	50.06	21.48
M. Rema2	96.92	74.74	22.18	92.03	74.91	17.12	88.24	75.3	12.94	84.08	71.55	12.53
Malakasiotikos	0.25	0.25	0	0.24	0.24	0	0.22	0.22	0	0.21	0.21	0
Mouzaki	8.27	8.27	0	7.85	7.85	0	7.53	7.53	0	7.17	7.17	0
Neoxoritis Fragma	0	0	0		0	0	0	0	0	0	0	0
Neoxoritis2	1.69	1.63	0.06	1.62	1.56	0.06	1.54	1.49	0.05	1.47	1.43	0.04
Neoxoritis3	11.2	9.2	2	10.69	8.78	1.91	10.19	7.97	2.22	9.73	8.35	1.38
N. Koziakas	9.89	9.89	0	9.42	9.42	0	9	9	0	8.59	8.59	0
Pamisson-Mesdani	62.95	41.63	21.32	60	42.1	17.9	57.29	42.46	14.83	54.68	40.54	14.14
Pinios-AliEfenti	30.33	19.43	10.9	28.87	19.78	9.09	27.61	20.12	7.49	26.33	19.19	7.14
Portaikos	55.62	47.93	7.69	53.09	45.48	7.61	50.6	43.14	7.46	48.33	44.8	3.53
Pyli	0.38	0.38	0	0.36	0.36	0	0.35	0.35	0	0.33	0.33	0
Sarakina	3.38	3.38	0	3.23	3.23	0	3.08	3.08	0	2.94	2.94	0
Total Volume	488.58	375.5	113.08	465.26	366.46	98.8	444.65	357.74	86.91	424.24	348.50	75.72

% Reduction in demand/ supply				5%	-2%	-13%	9%	-5%	-23%	13%	-7%	-33%
AEC (mio €)					1.93			4.84			8.79	
€/m^3 of water supply saved					0.21			0.27			0.33	

Agricultural Demand Node	Simulation with an irrigation efficiency increase by 20% (Karditsa) and 17% (Trikala)			Simulation with an irrigation efficiency increase by 25% (Karditsa) and 17% (Trikala)			Simulation with an irrigation efficiency increase by 29% (Karditsa) and 17% (Trikala)		
	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)	Water Demand (mio m^3)	Supply Delivered (mio m^3)	New Unmet Demand (mio m^3)
Ionas	5.39	5.39	0	5.39	5.39	0	5.39	5.39	0
Voula	2.43	2.43	0	2.43	2.43	0	2.43	2.43	0
B. Koziakas	2.72	2.29	0.43	2.72	2.29	0.43	2.72	2.29	0.43
Gavros	0.54	0.54	0	0.54	0.54	0	0.54	0.54	0
D. Koiti	12.37	11.83	0.54	12.37	11.82	0.55	12.37	12.08	0.29
Theopetra	2.09	1.85	0.24	2.09	1.85	0.24	2.09	1.85	0.24
K. Lithaios	63.09	50.7	12.39	63.09	50.64	12.45	63.09	53.02	10.07
Kleinovitikos	5.05	5.05	0	5.05	5.05	0	5.05	5.05	0
Lithaios	13.35	12.84	0.51	13.35	12.84	0.51	13.35	13.13	0.22
Loggas	0	0	0	0	0	0	0	0	0
M. Rema1	68.87	53.98	14.89	66.34	51.27	15.07	64.41	50.64	13.77
M. Rema2	80.73	72.11	8.62	77.39	72.56	4.83	74.85	70.18	4.67
Malakasiotikos	0.21	0.21	0	0.21	0.21	0	0.21	0.21	0
Mouzaki	6.89	6.89	0	6.6	6.6	0	6.39	6.39	0
Neoxoritis Fragma	0	0	0	0	0	0	0	0	0
Neoxoritis2	1.45	1.4	0.05	1.45	1.4	0.05	1.45	1.4	0.05
Neoxoritis3	9.57	8.37	1.2	9.57	8.37	1.2	9.57	8.58	0.99
N. Koziakas	8.34	8.34	0	8.17	8.17	0	8.03	8.03	0

Pamisson-Mesdani	53.39	45.8	7.59	52.73	47.65	5.08	52.2	49.08	3.12
Pinios-AliEfenti	25.57	21.37	4.2	25.02	22.27	2.75	24.59	22.64	1.95
Portaikos	47.54	46.53	1.01	47.54	46.5	1.04	47.54	47.54	0
Pyli	0.32	0.32	0	0.32	0.32	0	0.31	0.31	0
Sarakina	2.89	2.89	0	2.89	2.89	0	2.89	2.89	0
Total Volume	412.81	361.4	51.67	405.24	361.07	44.2	399.46	363.67	35.8
% Reduction in demand/ supply	16%	-4%	-54%	17%	-4%	-61%	18%	-3%	-68%
AEC (mio €)		11.31			13.04			14.45	
€/m^3 of water supply saved		0.80			0.90			1.22	

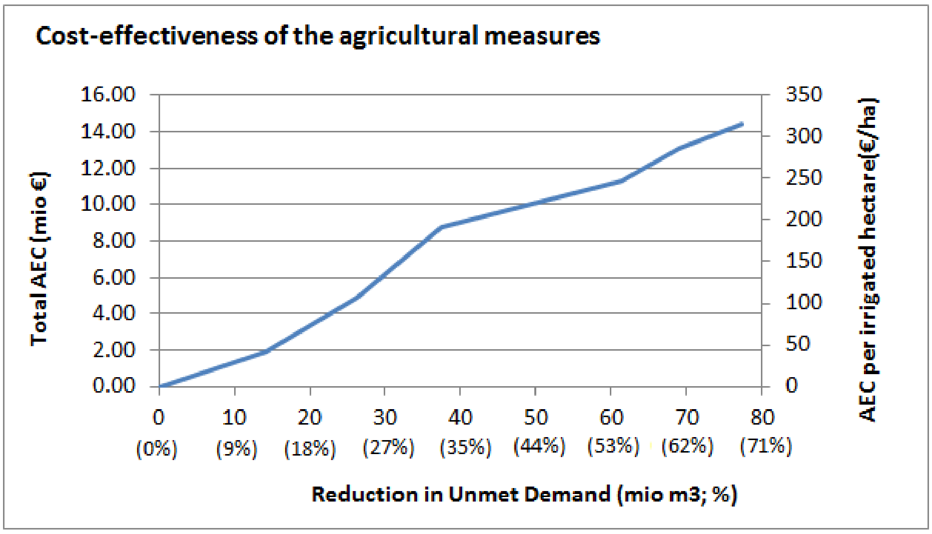


Figure 8.38: Cost-effectiveness of the agricultural measures with respect to the reduction achieved in the irrigation unmet demand

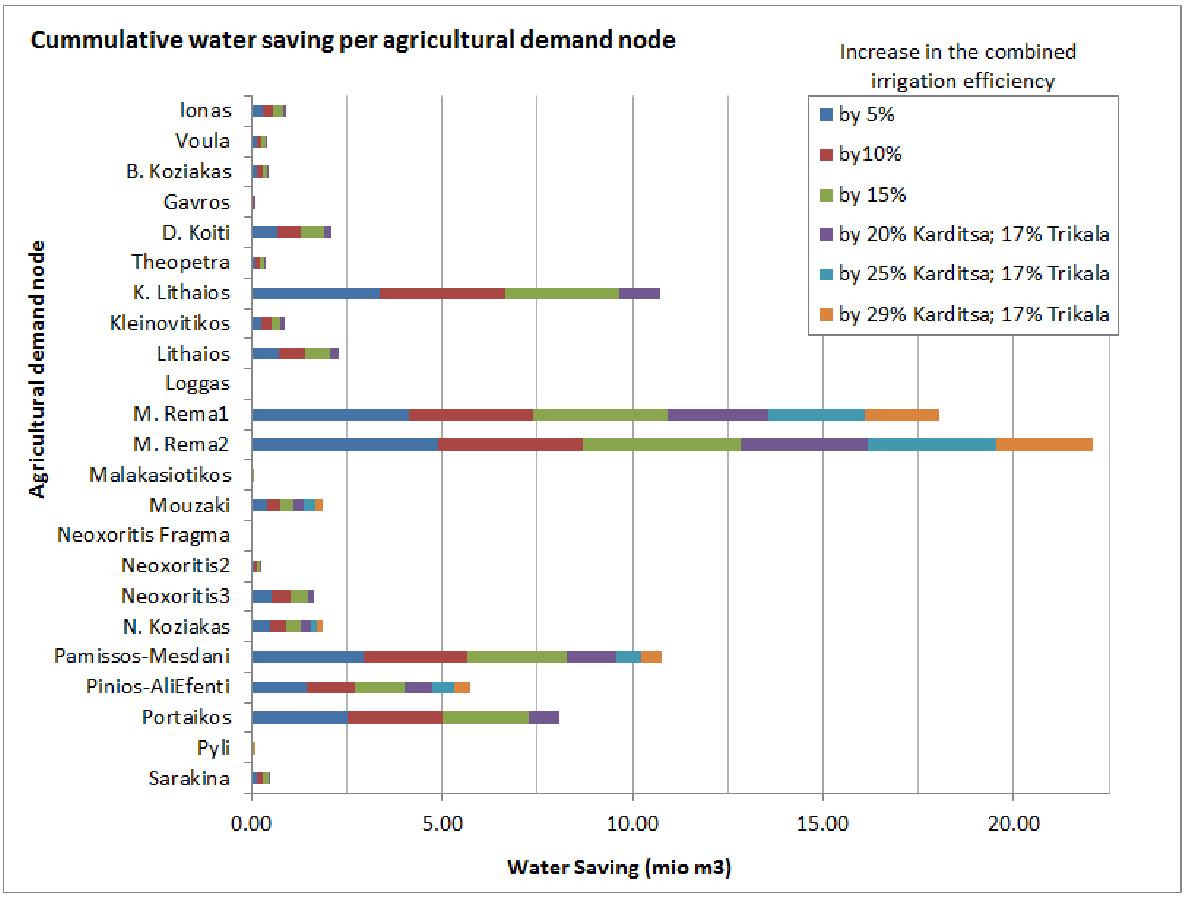


Figure 8.39: Overview of the cumulative water savings (moving from lower to the highest increase in irrigation efficiency) per agricultural demand node

8.7 Selection of optimum measures in the Ali-Efenti basin

The purpose of the global optimization for the case of Ali-Efenti has as an objective to reduce unmet water demand with the minimum possible investment. In order to minimize the unmet demand an analysis of the main consumers and options was undertaken in the previous Section 8.4.5. As previously discussed, the major users are the agriculture and urban sectors, while minor consumers include livestock and industry (Figure 8.16). As demonstrated in Table 8.32 below, for the baseline period (1995-2010) the irrigation and urban nodes have a mean annual water demand equal to 483.55 mio m^3 and 19.63 mio m^3 respectively. The unmet demand ranges from as low as 5 mio^3 m to 114 mio m^3 (in the very dry year 2007) (Figure 8.40), with a long-term annual average around 33.16 mio m^3, attributed to irrigation (99.5% of the unmet demand). An increasing trend in unmet demand is observed from 1995 to 2010 (Figure 8.40).

Table 8.32: Mean annual characteristics of water demand and supply in Ali-Efenti for the baseline period 1995-2010

Sector	Total Supply Delivered (mio m^3/yr)	Total Demand (mio m^3/yr)	Total Unmet Demand (mio m^3/yr)	Demand Coverage (%)
Domestic	19.63	19.63	0.00	100.00%
Irrigation	450.55	483.55	33.00	93.18%
Livestock	6.34	6.41	0.07	98.91%
Industry	1.79	1.88	0.09	95.21%
Total	**478.31**	**511.47**	**33.16**	**93.52%**

Table 8.33: Mean annual characteristics of water demand and supply in Pinios river for the year 2007 (worst year)

Sector	Total Supply Delivered (mio m^3/yr)	Total Demand (mio m^3/yr)	Total Unmet Demand (mio m^3/yr)	Demand Coverage (%)
Domestic	19.41	19.41	0.00	100.00%
Irrigation	375.52	488.57	113.08	76.86%
Livestock	6.02	6.41	0.40	93.92%
Industry	1.44	1.88	0.48	76.60%
Total	**402.39**	**516.27**	**113.96**	**77.94%**

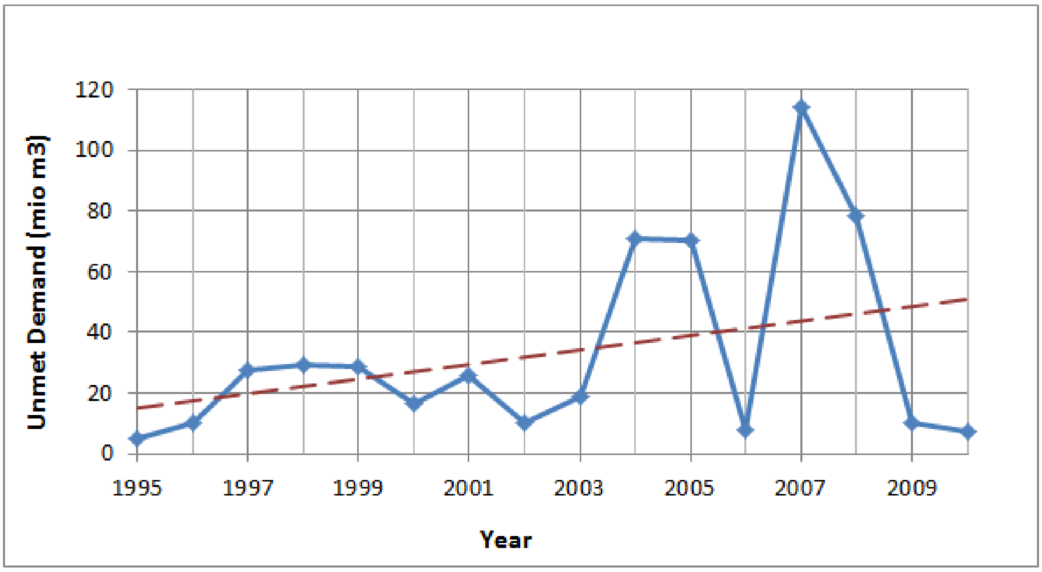


Figure 8.40: Unmet demand during the baseline period 1995-2010

The global optimization, implemented across both the urban and agricultural sectors, seeks to find the optimum mix of measures needed to be applied so that the optimization objectives are minimized. The developed DSS, aiming to support the global optimization process, includes three main components: the Ali-Efenti WRMM (developed in WEAP21) that simulates the hydrosystem, and Matlab that optimizes it, and the Intervention Curves that constitute the library/catalogue of measures. A bespoke code, handing the interaction between the two programs was developed in Matlab (Tsoukalas and Makropoulos, 2013), using the COM-API available in WEAP21, and the Matlab toolboxes are used for the optimization. The main loop of the optimization iterative process (as described in Chapter 6) begins with the transformation of the decision variables into an appropriate format, readable by WEAP21. Then, the connection to the WEAP21 opens through the COM-API, and WEAP21 reads the variables and calculates the results. The results are then exported to Matlab where the objective functions are calculated, and this iterative process is repeated until the stopping criteria are met. Two optimization scenarios were run: Scenario A incorporates 3 decision variables, namely the urban cost-effective curve, the agricultural cost-effective curve of Karditsa and the agricultural cost-effective curve of Trikala that were developed in the previous section. Scenario B incorporates one additional variable (thus 4 decision variables in total) namely the "deficit irrigation". Both scenarios have the same objectives. The Matlab Global optimization toolbox is used for the optimization, which incorporates the NSGA-II multi-objective algorithm. The population size is set to 15*numberOfVariables (i.e. 45 for Scenario A, and 60 for Scenario B) and the maximum generation number to 100. This resulted in 4,500 runs for scenario A and 6,000 runs for scenario B. The simulation period of the optimization was one year, the year with the highest unmet demand (Oct/2006 - Sept/2007) in order to minimize the computation time. That year had extreme drought conditions, and has therefore been chosen in order to optimize the system under the worst case conditions. Each run required approximately 10 minutes, thus the total computational time required for the optimization was about 31 days for scenario A and 42 days for scenario B. To reduce this time we used parallel computers.The lower and the upper limits of each decision variable relates to the corresponding cost-effective curves (Table 8.34).

Table 8.34: Lower and upper bounds of the decision variables

Decision Variable	Urban Curve	Karditsa Curve	Trikala Curve	Deficit irrigation
Lower bound	0 %	75.40 %	77.60 %	0 %
Upper bound	62.70 %	97.50 %	90.80 %	30.00 %

With regard to the additional decision variable “Deficit irrigation”, this was implemented in the WRMM WEAP21 with the use of a user-defined variable (DefIrr). The variable ranges between 0%-30%, and is used to limit the capacity of the irrigation transmissions links. If DefIrr is 30%, the maximum flow is limited to (100%-DeffIrr) = 70%. Thus, the water supplied, transmitted via the transmission links, will be reduced by 30%, and water demand is also reduced by the percent of deficit irrigation. This decrease in delivered supply due to deficit irrigation implies a decrease in crop yield, which consequently leads to a decrease in farmers' income. This basically means that there is a cost associated with deficit irrigation, and that the farmers bear this cost. These changes and cost impacts are taken into account by introducing into WEAP21 data on crop yields, as a function of water supply decrease, and crop market prices. The data input to the WRMM are presented in Table 8.35 below.

Table 8.35: Data entered into the WRMM to calculate farmers' income changes

Crop	Potential Yield (Ym) (Kg/m^2)	Producer Price (€/Kg)	Yield response factor to water stress (Ky)*
Alfalfa	1.360	0.190	1.10
Maize	1.037	0.185	1.25
Cotton	0.280	0.474	0.85
Sugarbeets	6.110	0.027	1.00
Orchards	1.800	0.400	1.30

*WEAP21 Crop library (FAO Irrigation and Drainage Paper No. 33, Doorenbos and Kassam, 1979)

Irrigation water deficits in crops, and the resulting water stress on the plant, have an effect on crop evapotranspiration and crop yield. The relationship between crop yield and water supply can be determined when crop water requirements and actual crop water use, on one hand, and maximum and actual crop yield on the other, are quantified. In the FAO Irrigation and Drainage Paper N° 56 approach (Allen et al., 1998), the response of yield to water supply is quantified by the yield response factor (Ky), which relates the relative actual vs. max potential yield decrease (1-Ya/Ym) to the relative evapotranspiration deficit (1-ETa/ETc). Hence, the Ky values for most crops are derived on the assumption that the relationship between relative yield (Ya/Ym) and relative evapotranspiration (ETa/ETc) is linear, and is valid for water deficits of up to about 50% or 1 - ETa/ETc = 0.5.

The Ky values are crop specific and vary over the growing season according to growth stages, with:

Ky>1: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress.

Ky<1: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use.

Ky=1: yield reduction is directly proportional to reduced water use.

In field conditions, water deficit of a given magnitude, expressed as the ratio of actual crop evapotranspiration (ETa) to potential crop evapotranspiration (ETc), may occur either continuously over the total growing period of the crop, or it may occur during any stage of the individual growth periods. FAO Irrigation and Drainage Paper Nº 33 (Doorenbos and Kassam, 1979) empirically derives yield-response factors (Ky) for individual growth stages (i.e. establishment, vegetative, flowering, yield formation, or ripening period) as well as for the total growing period. The equations below are used by WEAP21 in the Ali-Efenti WRMM to obtain the actual yield and the market value respectively:

$$Y_a = Y_m \cdot (1 - K_y \cdot (1 - \frac{ET_a}{ET_c})) \qquad (5)$$

Market Value = Y_a * Area * Price

Where:

Ya = actual yield (corresponding to ETa) [kg/ha],

Ym = maximum theoretical yield (corresponding to ETc) [kg/ha],

ETa = actual crop evapotranspiration,

ETc = potential crop evapotranspiration,

Ky = yield response factor to water stress,

Market Value = Total market value for crop [€],

Area = cultivated area [ha],

Price = unit market price for crop [€/kg]

The objective functions used in the two optimization scenarios are presented below. These objective functions, which concern unmet demand and supply delivered, are related only to agriculture. And this is because agriculture, in this case, has significantly higher demand than all the other uses. Also, the reliability of all other uses is relative high, i.e. domestic water demand has a coverage equal to 99.9%. The difference between Scenario A and B is the use of the decision variable "Deficit irrigation". Deficit irrigation can reduce unmet demand under the assumption that the farmers accept to demand less water under a specific cost. That cost is calculated as a change in farmers' income.

<u>Optimization scenario A:</u>

Objective 1: MIN (Σ Agricultural Unmet Demand)

Objective 2 : MIN (Σ AEC Investrment Cost - Farmers' Income Change)

Note that in this case the decision variable "*Deficit irrigation*" is not taken into account.

<u>Optimization scenario B:</u>

Objective 1 : MIN (Σ Agricultural Unmet Demand)

Objective 2 : MIN (Σ AEC Investrment Cost - Farmers' Income Change)

Note that in this case the decision variable "*Deficit irrigation*" is taken into account.

The results of the global optimization in the Ali-Efenti basin are presented in Figure 8.41 (for Scenario A) and Figure 8.42 (for Scenario B). The baseline situation, with zero investment cost, has an unmet demand equal to 114 mio m^3 and supply delivered of 402 mio m^3. For scenario A, as demonstrated by the pareto front, the maximum achievable unmet demand is about 22 mio m^3 (i.e. 80% reduction) with an investment cost about 18 million euro per year, and the supply delivered in this case is close to 306 mio m^3. After that point the improvement is minimum, dropping the unmet demand to 19 mio m³ with an investment cost of approximately 49 million euros per year. For that reason, it is suggested that investments above 18 million euro AEC could be disregarded. Some indicative optimization results (selected solutions of the pareto front) that deliver unmet demand reductions ranging from 10-80%, are presented in Table 8.36 and Table 8.37. For example, a 50% reduction in the unmet demand (ref. to solution No. 5 in Table 8.36 and Table 8.37) requires an investment of 7.7 mio € AEC (equivalent to 0.14 €/m³ saved) and entails measures that will lead to a 12% increase in urban water savings, a 18% increase in Karditsa irrigation efficiency and a 10% increase in Trikala irrigation efficiency. These increases translate into specific measures implementation, according to the intervention curves, as presented in Table 8.38 and Table 8.39.

We can observe that the agricultural interventions are overall preferred by the algorithm. The implementation of urban water saving measures does not contribute significantly to the reduction of unmet demand, and this is because the urban cost-effective curve has a very flat slope above the water saving potential of 7 mio m³ (i.e. small additional savings require high AEC) and because the urban water use (and thus the saving potential) is very small compared to agriculture. The algorithm prefers solutions which are associated with irrigation efficiency gains in the Karditsa prefecture. The AEC in € for each m³ saved are in the range of 0.10-0.20 for up to 80% reduction in unmet demand (i.e. about 90 mio m³ of water saved).

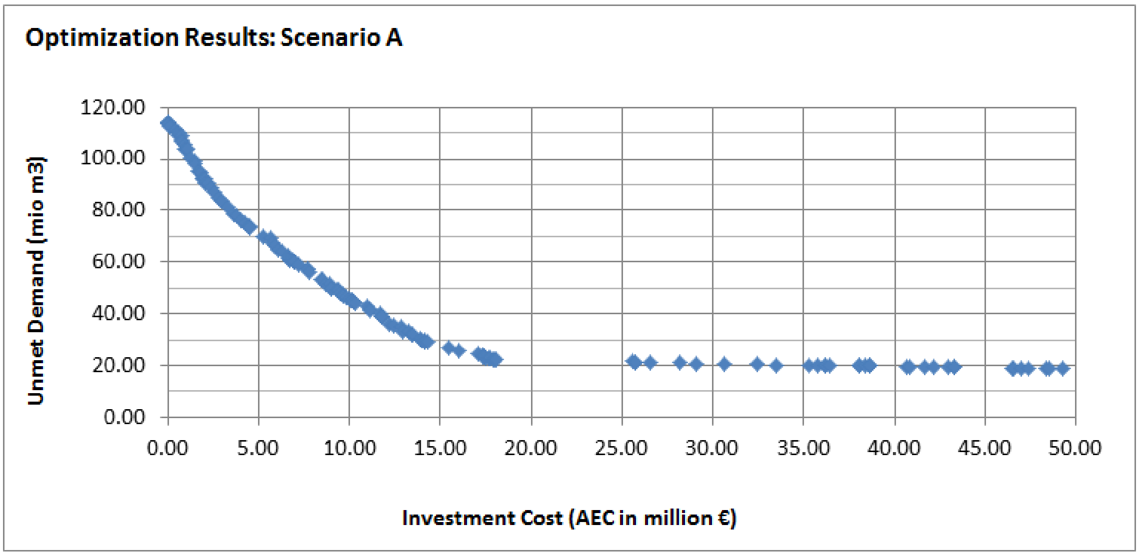


Figure 8.41: Pareto front of optimization scenario A

Table 8.36: Indicative results (pareto front solutions) of optimization scenario A

Optimization objectives	Decision Variables (resulting values)

Solution #	Unmet Demand (mio m³)	Investment cost (AEC) (mio €)	WSu	Karditsa Irrigation Efficiency	Trikala Irrigation Efficiency
0	113.96	0.00	0.00%	75.40%	77.60%
1	103.61	1.10	1.33%	78.48%	79.14%
2	90.70	2.07	2.03%	82.24%	80.09%
3	78.60	3.63	9.41%	83.05%	82.87%
4	67.46	5.73	8.08%	86.81%	83.79%
5	57.58	7.69	11.52%	88.70%	85.57%
6	45.31	10.06	12.92%	88.91%	89.83%
7	34.87	12.80	2.04%	94.75%	90.23%
8	22.78	17.75	35.27%	97.19%	90.79%
9	18.88	49.25	53.73%	97.46%	90.77%

Table 8.37: Water saving and irrigation efficiency gains from the selected pareto solutions on scenario A

Solution #	Water savings (mio m³)	% Reduction in Unmet Demand	Investment cost (AEC) (€/m³ saved)	% Increase WSu	% Increase in Karditsa Irrigation Efficiency	% Increase in Trikala Irrigation Efficiency
0	0.00	0%	0.00	0%	0%	0%
1	10.35	9%	0.11	1%	4%	2%
2	23.26	20%	0.09	2%	9%	3%
3	35.36	31%	0.10	9%	10%	7%
4	46.50	41%	0.12	8%	15%	8%
5	56.38	49%	0.14	12%	18%	10%
6	68.65	60%	0.15	13%	18%	16%
7	79.09	69%	0.16	2%	26%	16%
8	91.18	80%	0.19	35%	29%	17%
9	95.08	83%	0.52	54%	29%	17%

Table 8.38: Translation of the different solutions (of scenario A) into specific measures to be applied in the urban sector

Solution #	% Increase WSu	Penetration (% of the households adapting the measure)						
		Dual flush toilet	Shower-heads (1 item)	Low flow taps (2 items)	Efficient Washing Machine	Dish-washer	RWH	GWR
0	0%	-	-	-	-	-	-	-
1	1%	3%	4%	-	-	-	-	-
2	2%	7%	8%	-	-	-	-	-
3	9%	-	47%	-	-	-	-	-

4	8%	-	38%	-	-	-	-	-
5	12%	-	55%	-	-	-	-	-
6	13%	-	62%	-	-	-	-	-
7	2%	7%	8%	-	-	-	-	-
8	35%	96%	100%	85%	-	-	-	-
9	54%	100%	100%	100%	100%	100%	18%	93%

Table 8.39: Translation of the different solutions (of scenario A) into specific measures to be applied in the agricultural sector

Solution #	% Increases in Irrigation Efficiency	Penetration (ha of land irrigated with this method)			
		Furrow	Sprinklers	Drip	Precision Agriculture*
0	Karditsa: 0% Trikala: 0%	686 204	18,671 22,141	1,062 5,255	0 0
1	Karditsa: 4% Trikala: 2%	631 85	17,692 21,961	2,096 5,553	145 2,418
2	Karditsa: 9% Trikala: 3%	198 25	16,787 22,074	3,433 5,500	236 4,041
3	Karditsa: 10% Trikala: 7%	167 15	16,736 19,576	3,517 8,010	499 7,821
4	Karditsa: 15% Trikala: 8%	117 14	14,030 18,389	6,273 9,198	3,712 9012
5	Karditsa: 18% Trikala: 10%	115 15	12,223 16,254	8,081 11,333	5,475 11,183
6	Karditsa: 18% Trikala: 16%	117 15	12,133 11,226	8,169 16,358	5,591 16,216
7	Karditsa: 26% Trikala: 16%	110 15	6,906 10,746	13,403 16,840	10,827 16,695
8	Karditsa: 29% Trikala: 17%	109 14	4,915 10,037	15,395 17,550	12,841 17,406
9	Karditsa: 29% Trikala: 17%	109 14	4,587 10,037	15,724 17,550	13,172 17,406

* The hectares where Precision Agriculture (PA) is applied are part of the hectares under drip irrigation

For Scenario B (which incorporates the additional decision variable of deficit irrigation -DeffIrr), it is observed, as demonstrated by the pareto front, that an investment of about 8.5 mio € AEC can eliminate unmet demand and result in full coverage of the water needs (Figure 8.42). This of course entails the application of 20% deficit irrigation. After that point further investments result in water surplus, up to 82 mio m^3 with an investment cost of approximately 24 million euro per year and a 30% deficit irrigation (Figure 8.42). Some indicative optimization results (selected solutions of the pareto front) that deliver unmet demand reductions ranging from 10-100% and water surplus (from 4-70% over the original unmet demand) are presented in Table 8.40 and Table 8.41. For example, an approximately 50% reduction in the unmet demand (ref. to solution No. 5 in Table 8.40 and Table 8.41) requires an investment of 4.6 mio € AEC (equivalent to 0.08€/m^3 saved) and entails measures that will lead to a 13.5% increase in urban water savings, a 12% increase in Karditsa irrigation efficiency and a 3% increase in Trikala irrigation efficiency, and the application of 5.2% deficit irrigation. Water sufficiency (i.e. full coverage of the water needs and no unmet demand) can be achieved with an investment of about 8.5 mio € AEC (equivalent to 0.08€/m^3 saved) and entails measures that will lead to a 11.5% increase in urban water savings, an 8% increase in Karditsa irrigation efficiency and a 2% increase in Trikala irrigation efficiency, and the application of 19% deficit irrigation. These increases translate into specific measures implementation, according to the intervention curves, as presented in Table 8.42 and Table 8.43. We can observe that in the beginning (for a reduction in unmet demand up to 50%) the algorithm choses to implement up to 13% savings in the urban sector (i.e. the cheap interventions in this sector), increase the Karditsa and Trikala irrigation efficiencies up to 12% and 8% respectively, and gradually introduce deficit irrigation up to 5%, resulting in an overall saving of 60 mio m^3. To jump above this level of water saving, deficit irrigation needs to significantly increase up to 22% in order to achieve a full coverage of water needs (100% reduction of unmet demand). In other words, the algorithm decides to use extensively deficit irrigation due to the lower cost and higher benefit. In this case, the key factor is the farmer's loss income which is incorporated in the investment cost. In order to obtain a surplus of about 30 mio m^3 a 28% deficit irrigation must be applied, while to reach the maximum potential surplus of 80 mio m^3 substantial urban saving (32%) and irrigation efficiency gains (25% in Karditsa and 9.5% in Trikala) are additionally required. Finally, it worth noticing that investments ranging from zero to 11.5 mio € per year produce water savings at higher rates (i.e. the slope of the curve at this part is steeper). Beyond that level (which renders about 140 mio m^3 saved), the investment must almost double in order to achieve an additional 50 mio m^3 saved (i.e. almost 1/3 of what already saved). This is caused by the fact that significant urban saving must be achieved which entails the application of more expensive urban interventions, as well significant irrigation efficiency gains in Karditsa.

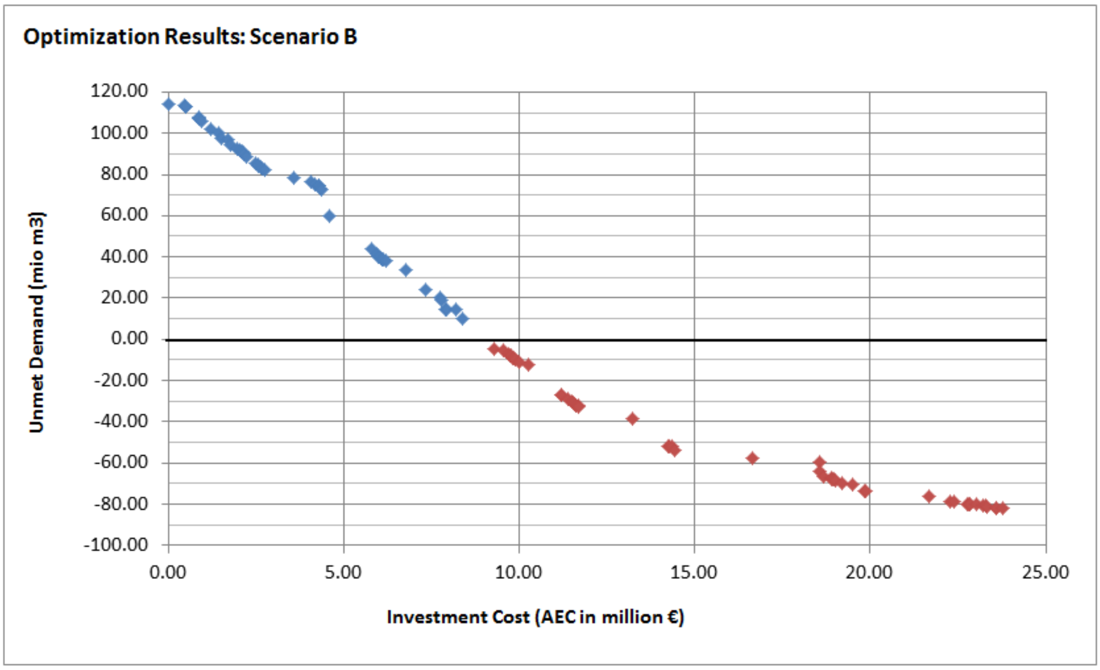


Figure 8.42: Pareto front of optimization scenario B

Table 8.40: Indicative results (pareto front solutions) of optimization scenario B

Optimization objectives			Decision Variables (resulting values)			
Solution #	Unmet Demand (mio m^3)	Investment cost (AEC) (mio €)	WSu	Karditsa Irrigation Efficiency	Trikala Irrigation Efficiency	Deficit Irrigation
0	113.96	0.00	0.00%	75.40%	77.60%	0.00%
1	101.74	1.22	7.39%	79.12%	78.55%	0.21%
2	91.18	2.08	7.29%	81.86%	78.05%	1.34%
3	78.72	3.59	10.24%	77.23%	83.27%	2.90%
4	72.45	4.34	12.02%	77.25%	84.10%	3.65%
5	60.13	4.58	13.50%	84.08%	80.17%	5.20%
6	43.63	5.80	7.10%	84.49%	80.17%	8.88%
7	33.88	6.77	3.66%	84.67%	80.18%	11.07%
8	24.11	7.33	7.13%	83.01%	79.62%	14.16%
9	10.08	8.38	11.52%	82.59%	78.86%	17.65%
10*	-4.63	9.27	0.90%	80.63%	79.85%	21.51%
11*	-11.06	9.98	14.38%	80.88%	79.89%	22.22%
12*	-32.98	11.69	3.42%	80.49%	79.41%	27.77%
13*	-57.40	16.63	0.12%	84.10%	88.64%	27.51%
14*	-79.77	22.79	32.31%	92.91%	84.79%	29.99%
15*	-82.02	23.78	34.04%	93.97%	85.05%	29.99%

*Solutions 10-15 achieve zero unmet demand and further deliver a water surplus

Table 8.41: Water saving and irrigation efficiency gains from the selected pareto solutions on scenario B

Solution #	Water savings (mio m³)	% Reduction in Unmet Demand	Investment cost (AEC) (€/m³ saved)	% Increase Wsu	% Increase in Karditsa Irrigation Efficiency	% Increase in Trikala Irrigation Efficiency	% Deficit Irrigation
0	0.00	0%	0.000	0.00%	0.00%	0.00%	0.00%
1	12.22	11%	0.100	7.39%	5.07%	1.22%	0.21%
2	22.78	20%	0.091	7.29%	8.72%	0.58%	1.34%
3	35.24	31%	0.102	10.24%	2.57%	7.31%	2.90%
4	41.51	36%	0.105	12.02%	2.58%	8.37%	3.65%
5	53.83	47%	0.085	13.50%	11.66%	3.31%	5.20%
6	70.33	62%	0.083	7.10%	12.21%	3.31%	8.88%
7	80.08	70%	0.084	3.66%	12.45%	3.33%	11.07%
8	89.85	79%	0.082	7.13%	10.24%	2.60%	14.16%
9	103.88	91%	0.081	11.52%	9.68%	1.63%	17.65%
10	118.59	104%	0.078	0.90%	7.08%	2.90%	21.51%
11	125.02	110%	0.080	14.38%	7.41%	2.95%	22.22%
12	146.94	129%	0.080	3.42%	6.89%	2.34%	27.77%
13	171.36	150%	0.097	0.12%	11.69%	14.23%	27.51%
14	193.73	170.0%	0.118	32.31%	23.39%	9.27%	29.99%
15	195.98	172%	0.121	34.04%	24.79%	9.60%	29.99%

Table 8.42: Translation of the different solutions (of scenario B) into specific measures to be applied in the urban sector

Solution #	% Increase Wsu	Penetration (% of the households adapting the measure)						
		Dual flush toilet	Shower-heads (1 item)	Low flow taps (2 items)	Efficient Washing Machine	Dish-washer	RWH	GWR
0	0.00%	-	-	-	-	-	-	-
1	7.39%	-	38%	-	-	-	-	-
2	7.29%		38%	-	-	-	-	-
3	10.24%	-	47%	-	-	-	-	-
4	12.02%	-	61%	-	-	-	-	-
5	13.50%	-	67%	-	-	-	-	-
6	7.10%	-	38%	-	-	-	-	-
7	3.66%	8%	8%	-	-	-	-	-
8	7.13%	-	38%	-	-	-	-	-
9	11.52%	-	55%	-	-	-	-	-
10	0.90%	3%	3%	-	-	-	-	-

11	14.38%	-	76%	-	-	-	-	-
12	3.42%	8%	8%	-	-	-	-	-
13	0.12%	3%	4%	-	-	-	-	-
14	32.31%	76%	100%	66%	-	-	-	-
15	34.04%	91%	100%	70%	-	-	-	-

Table 8.43: Translation of the different solutions (of scenario B) into specific measures to be applied in the agricultural sector

Solution #	% Increases in Irrigation Efficiency	Penetration (ha of land irrigated with this method)			
		Furrow	Sprinklers	Drip	Precision Agriculture*
0	Karditsa: 0%	686	18,671	1,062	0
	Trikala: 0%	204	22,141	5,255	0
1	Karditsa: 5%	655	17,437	2,327	81
	Trikala: 1%	91	22,121	5,388	980
2	Karditsa: 9%	476	16,631	3,313	472
	Trikala: 1%	154	22,153	5,295	686
3	Karditsa: 3%	665	18,083	1,671	45
	Trikala: 7%	16	18,928	8,657	8,408
4	Karditsa: 3%	665	18,083	1,671	45
	Trikala: 8%	15	18,012	9,573	9,355
5	Karditsa: 12%	121	16,337	3,961	1,355
	Trikala: 3%	60	22,045	5,496	4,445
6	Karditsa: 12%	117	15,994	4,309	1,739
	Trikala: 3%	60	22,045	5,496	4,445
7	Karditsa: 12%	116	15,915	4,388	1,748
	Trikala: 3%	60	22,045	5,496	4,445
8	Karditsa: 10%	167	16,736	3,517	499
	Trikala: 3%	101	22,088	5,412	3,461
9	Karditsa: 10%	198	16,787	3,433	236
	Trikala: 2%	86	22,108	5,406	2,161
10	Karditsa: 7%	619	16,905	2,896	166
	Trikala: 3%	25	22,074	5,500	4,041
11	Karditsa: 7%	576	16,867	2,976	128
	Trikala: 3%	25	22,074	5,500	4,041
12	Karditsa: 7%	619	16,905	2,896	166
	Trikala: 2%	104	22,069	5,427	3,337
13	Karditsa: 12%	121	16,337	3,961	1,355
	Trikala: 14%	14	12,632	14,953	14,779
14	Karditsa: 23%	113	8,453	11,853	9,168
	Trikala: 9%	15	17,196	10,390	10,235
15	Karditsa: 25%	114	7,631	12,674	10,074
	Trikala: 10%	15	16,948	10,637	10,476

* The hectares where Precision Agriculture (PA) is applied are part of the hectares under drip irrigation

A comparison across the two optimization scenarios (Figure 8.43, Table 8.44) shows that at the beginning, for water savings up to 40 mio m³ (i.e. about 30% reduction of the unmet demand) both scenarios have similar cost-effectiveness (investment cost of up to 4 mio € per year or 0.1

AEC €/m³ saved), since scenario B applies small percentages of deficit irrigation up to 3%. After that point, the cost-effectiveness of the two scenarios strongly deviates, with scenario B delivering higher water savings at a lower cost. For example, to achieve about 70% reduction in the unmet demand (i.e. 80 mio m³ saved) the cost of scenario A is double than that of scenario B and this is due to the fact that scenario B introduces significant deficit irrigation as opposed to more expensive urban and agricultural measures. Scenario B clearly demonstrates that by introducing deficit irrigation up to 30%, the unmet demand can be eliminated, while a substantial water surplus can be generated, which is not the case in scenario A. Furthermore, the overall costs are lower than those of scenario A, highlighting thus the potential benefits of deficit irrigation.

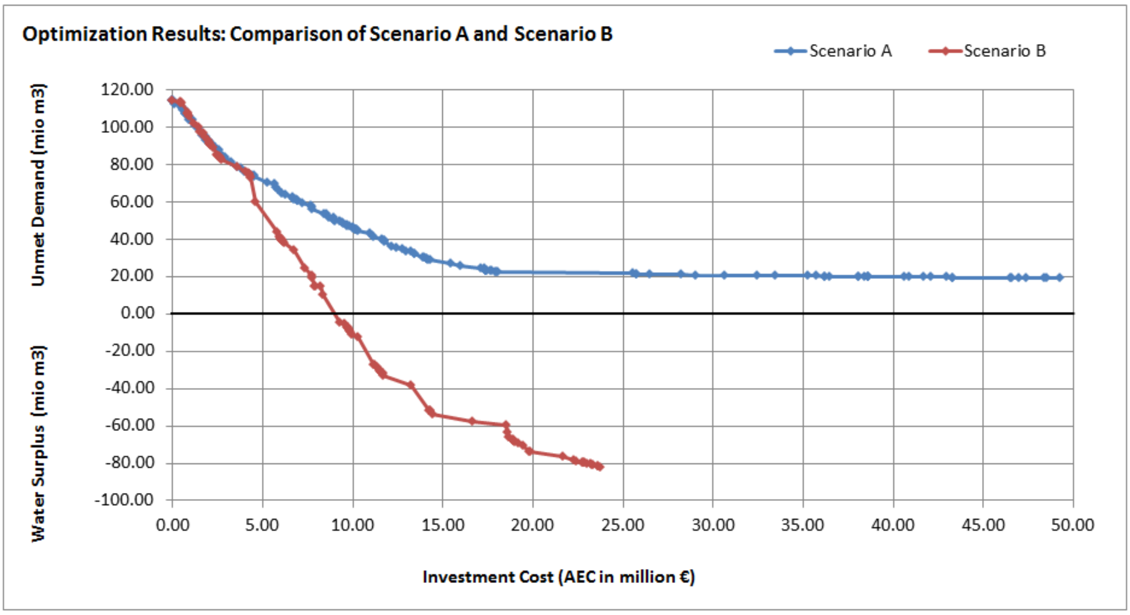


Figure 8.43: Comparison of the Pareto fronts of the optimization scenarios A and B

Table 8.44: Comparison of indicative solutions (delivering the same reduction in unmet demand) of the two optimization scenarios

% Reduction in Unmet Demand	Optimization Scenario	Investment cost (AEC) (mio €)	% Increase WSu	% Increase in Karditsa Irrigation Efficiency	% Increase in Trikala Irrigation Efficiency	% Deficit Irrigation
~ 20%	A	2.07	2%	9%	3%	-
	B	2.08	7%	9%	0.5%	1%
~ 30%	A	3.63	9%	10%	7%	-
	B	3.59	10%	2.5%	7%	3%
~ 50%	A	7.69	12%	18%	10%	

	B	**4.58**	13.5%	12%	3%	5%
~ 70%	A	12.80	2%	26%	16%	
	B	**6.77**	4%	12.5%	3%	11%
~ 80%	A	17.75	35%	29%	17%	
	B	**7.33**	7%	10%	3%	14%

8.8 Indicative Policy Targets for internalising drought risk management in the Ali-Efenti basin

8.8.1 Development of future climate change and socio-economic scenarios

8.8.1.1 The Climate Change scenario A1B

For the analysis of droughts, and signals indicating future droughts' activity in the Ali-Efenti River Basin, the IPCC A1B scenario (Nakicenovic et al., 2000) has been selected since it is more balanced (Alcamo et al., 2007), assuming a balanced mix of technologies and supply sources, defined as not relying too heavily on one particular energy source, and based on the assumption that similar improvement rates apply to all energy supply and end-use technologies. The climate change projections of the A1B scenario for the Ali-Efenti have been based on regional downscaled Global Circulation Models (GCMs) and Regional Circulation Models (RCMs) produced by the EU project ENSEMBLES[1]. These timeseries have been bias corrected and available at a 25 x 25 km resolution. The added value of these datasets relies on the fact that the ensemble prediction system for climate change is based on the principal state-of-the-art, high resolution, Global and Regional Earth System Models developed in Europe, validated against quality-controlled, high-resolution gridded datasets for Europe, and has produced for the first time an objective probabilistic estimate of uncertainty in future climate at the seasonal to decadal and longer time-scales. The timeseries for the Ali-Efenti have been obtained from the National Observatory of Athens (NOA, project partner of the ENSEMBLES) downscaled from the model RACMO2_v2.1[2], developed by the Royal Netherlands Meteorological Institute-KNMI (Lenderink et al. 2003, 2007). The driving global model used in the process is the ECHMA5 for the A1B scenario. The physics package of RACMO2 is based on ECMWF model cycle 23 release 4

[1] The ENSEMBLES project (contract number GOCE-CT-2003-505539) was supported by the European Commission's 6th Framework Programme as a 5 year Integrated Project from 2004-2009 under the Thematic Sub-Priority "Global Change and Ecosystems". http://ensembles-eu.metoffice.com/about.html; www.ensembles-eu.org

[2] Documentation on RACMO2 can be found in White, P.W. (ed.), 2002. Physical processes (CY23R4). Information on the performance of RACMO2.0 and physics updates with respect to original ECMWF formulation are described in:

G. Lenderink, B. van den Hurk, E. van Meijgaard, A.van Ulden and J. Cuijpers, 2003. Simulation of present-day climate in RACMO2: first results and model developments, KNMI, Technical Report 252, 24 pp.;

C. de Bruijn and E. van Meijgaard, 2005. Verification of HIRLAM with ECMWF physics compared with HIRLAM reference versions, HIRLAM Technical Report 63, 39 pp.

(ECMWF - European Centre for Medium-range Weather Forecasts) . Regarding the models' characteristics, the external forcings are presented below:

- Solar constant: 1370 W/m^2
- GHG-concentrations in the period 1961-2000 follow linear trends adopted from SAR:

GHG	**units**	**Reference value 1990**	**Annual trend**
CO_2	ppmv	353.0	1.5
CH_4	ppmv	1.720	0.012
N_2O	ppbv	310.0	0.8
CFC_{11}	pptv	280.0	9.5
CFC_{12}	pptv	484.0	17.0

- Ozone: climatology distributing the ozone mixing ratio as a function of pressure, latitude and month following Fortuin and Langematz (1994; Atmos. Sensing and Modeling, 2311, 207-216)
- Aerosols: four types of aerosols (maritime, continental, urban, desert) geographically distributed according to Tanre climatology (1984; in Aerosols and Their Climatic Effects, 133-177).

Climate change impacts in the near future, based on the IPCC A1B scenario and on data downscaled by the RACMO2 model, have been studied for the whole Greek territory (Giannakopoulos et al., 2011). The results provide insights into particular regions of the Greek territory that may undergo substantial impacts due to climate change, the Thessaly being one of them. In that study particular attention has been paid to the climatic indicators related to the agricultural sector, namely changes in the mean precipitation, drought duration, number of wet and dry spells, and changes in the growing season. These indicators are presented in Table 8.45. Each annual parameter is calculated from the RACMO2 daily output and then averaged for both the control (1961–1990) and the future period (2021–2050). For spell type indicators (e.g. max length of summer days, max length of dry spell with P< 1 mm), the annual longest spell is calculated for each year and then averaged over both the future (2021-2050) and the control period (1961-1990). The general picture results in small overall reductions in annual precipitation. Substantial changes in some of these indices exhibit significant environmental implications in the domain of study (e.g. desertification, land degradation, etc.).

Table 8.45: Indicators related to climate change impacts in the Thessaly area

Indicator	Expression/estimation	Result	Comment	Uncertainty*
Winter Precipitation	Sum of daily precipitation for the winter period of each year, averaged for the future (2021-2050) and control period (1961-1990)	-10%	Winter season is discussed since the agriculture of Thessaly strongly relies on winter rainfall.	This change is associated with large uncertainties, bigger than the change itself.
Autumn Precipitation	Sum of daily precipitation for the fall period of each year, averaged for the future (2021-2050) and control period (1961-1990)	+20%	Winter season is discussed since the agriculture of Thessaly strongly relies on autumn rainfall.	The 95th percentile confidence range in this projection ranges from 30 to 50%.
Maximum length of dry spell (in days)	Number of consecutive days with precipitation less than 1 mm per day (P<1mm). For each year the annual longest spell has been calculated (# of days) and then averaged for the future (2021-2050) and the control period (1961-1990)	+ 15 days	Increasing trends in the number of consecutive dry days can be indicative that the problem of drought and desertification gets intensified.	The confidence range value of this change is as big as the change itself, implying large uncertainties, resulting from the episodic nature of precipitation affecting dry spell length
Number of heatwave days	Number of days where maximum temperatures exceed 35 ^{0}C (Tmax > 35 ^{0}C)	+ 20 days	Under such temperature conditions, the productive stage of crops may be unfavorably affected.	Confidence range varies from ±3 to ±7 days.
Growing Season (in days)	Growing season is defined as the season with favorable conditions for crop growth. Changes in growing season length are defined as the changes in the number of days between the last day of spring frost and the first day of autumn frost	+15 days	Crop growing season length increases as a result of the earlier ending and later starting frosts of spring and autumn, respectively.	The confidence range for the growing season estimates varies from ±2 to ±7 days
Frost nights	Number of days where minimum temperatures are below 0 ^{0}C (Tmin < 0 ^{0}C)	-10 days	This is a very important factor for agricultural areas, especially where sensitive crops exist.	Uncertainty estimates for this parameter range from ±2 to ±7 days.

Source: Giannakopoulos et al., 2011

* Climate projections are associated with uncertainties stemming from the different socioeconomic assumptions that affect projections of greenhouse gas emissions (GHG), radiative forcing, climate system responses and feedbacks. To quantify uncertainty this study used bootstrapping methodology by artificially producing the 30-year differences of each parameter between the two periods. Each sample consisted of 30 values which were resampled 1,000 times with replacement. In each resample, the mean was calculated and the 95th percentile confidence intervals were c then computed from the resulting series. Thus, in the analysis performed, each mean parameter change is presented with a (±a) value which represents the confidence range value to add or subtract from the mean difference to get the limits. This is used as a measure to assess the confidence in the results.

For the specific analysis of the future climate change (under the A1B scenario) in the Ali-Efenti basin, daily timeseries of minimum temperature, maximum temperature and precipitation have been obtained from the RACMO2 model output for the period 1960-2030 from 31 locations (output nodes) in the vicinity on the entire Pinios River Basin area, and then the ones located in the Ali-Efenti catchment have been selected. The period 1961-1990 has been used as baseline (control run) for comparison with the 2015-2030 which covers the future selected target year 2026. This target year has been chosen to meet the policy makers and stakeholders' needs and support planning in the near future. Additionally, the modelled timeseries of the RACMO2 for the period 1975-2010 have been compared with observed timeseries, measured in raingauges of the Ali-Efenti during the same years, in order to obtain an estimation of how well the model output compares to measured field data. The locations of the RACMO2 output nodes have been selected to match as close as possible the location of the Ali-Efenti existing raingauges and are illustrate in Figure 8.44.

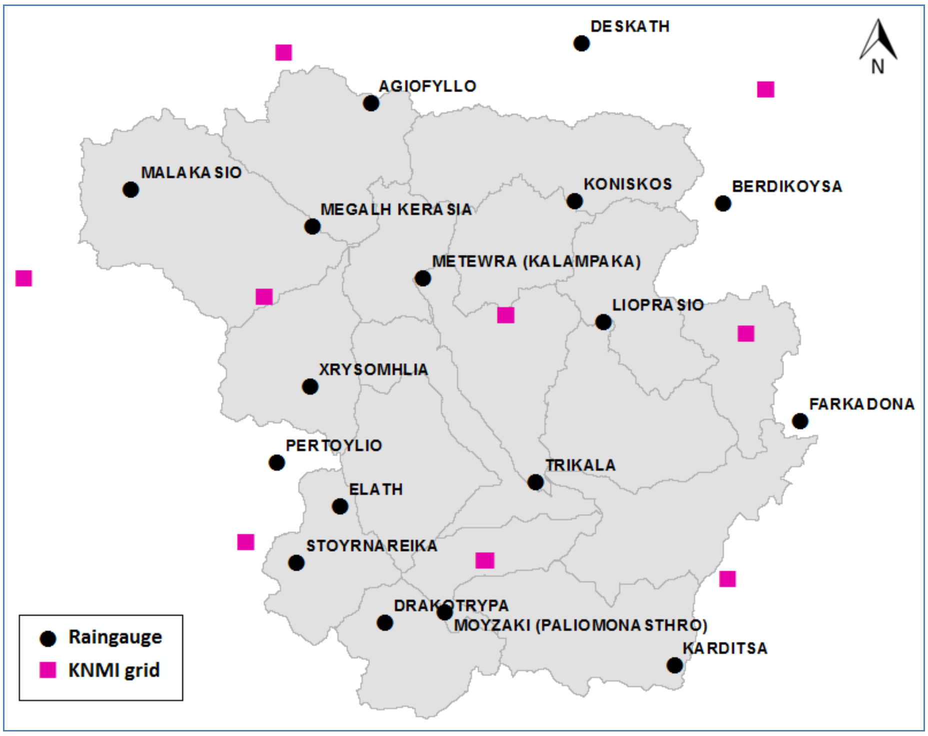


Figure 8.44: Location of RACMO2 output nodes (KNMI grid) and the Ali-Efenti raingauges

The mean daily precipitation and temperature for the period 2015-2030 has been calculated for each grid node, as well as the moving averages for the subsequent 5-year periods 2015-2019, 2016-2020 … 2026-2030 to identify trends. The results are presented in Table 8.46 below. The percent change (%) in the mean daily precipitation and the number of dry days per year between the baseline period 1961-1990 and the future 2015-2030 have also been estimated for each location. The resulting point values have been interpolated, using a kriging method, to obtain a coverage for the entire study area, and assess the spatial distribution of these indicators (Figure 8.45 and Figure 8.46). It is observed that in some locations the mean daily precipitation is expected to decrease while in other locations it is expected to increase. More specifically, a clear divide is observed, with decreasing trends of the mean daily precipitation in the northern part of the Ali-Efenti (around 3% decrease), while increasing in the southern part of the basin (around 1-2%). With regard to the number of dry days per year, these are projected to increase. A higher increase in the number of dry days is expected in the southern and the northwestern part (up to 5% and 6% respectively), and a less prominent increase is expected in the northeastern part (around 3.5-4%).

Table 8.46: Mean daily precipitation across the periods 1961-1990 and 2015-2030

KNMI node	RAMCO baseline (control run)	RAMCO future period	moving 5-yr periods											
	1961-1990	2015-2030	*2015-2019*	*2016-2020*	*2017-2021*	*2018-2022*	*2019-2023*	*2020-2024*	*2021-2025*	*2022-2026*	*2023-2027*	*2024-2028*	*2025-2029*	*2026-2030*
200088	1,39	**1,36**	1,30	1,22	1,39	1,40	1,44	1,51	1,46	1,45	1,25	1,24	1,26	1,31
200093	1,96	**1,92**	1,91	1,75	1,85	1,92	1,94	2,08	2,04	2,02	1,78	1,78	1,78	1,85
200098	1,66	**1,59**	1,53	1,45	1,54	1,66	1,70	1,78	1,69	1,72	1,47	1,48	1,49	1,55
200099	2,93	**2,87**	2,68	2,67	2,98	2,93	3,06	3,17	3,06	3,18	2,80	2,87	2,83	2,80
200101	3,43	**3,32**	3,14	3,14	3,48	3,26	3,41	3,59	3,45	3,65	3,28	3,39	3,25	3,22
200102	2,38	**2,31**	2,18	2,12	2,30	2,39	2,46	2,56	2,46	2,54	2,18	2,20	2,21	2,24
200103	1,37	**1,33**	1,23	1,17	1,31	1,43	1,48	1,52	1,44	1,44	1,22	1,19	1,25	1,33
200105	0,87	**0,86**	0,78	0,72	0,86	0,89	0,94	0,98	0,93	0,92	0,79	0,76	0,81	0,87
200122	0,95	**0,97**	0,89	0,82	0,92	1,06	1,10	1,12	1,08	1,07	0,89	0,84	0,93	0,97

*Red colour denotes a decrease from the baseline; Blue colour denotes an increase.

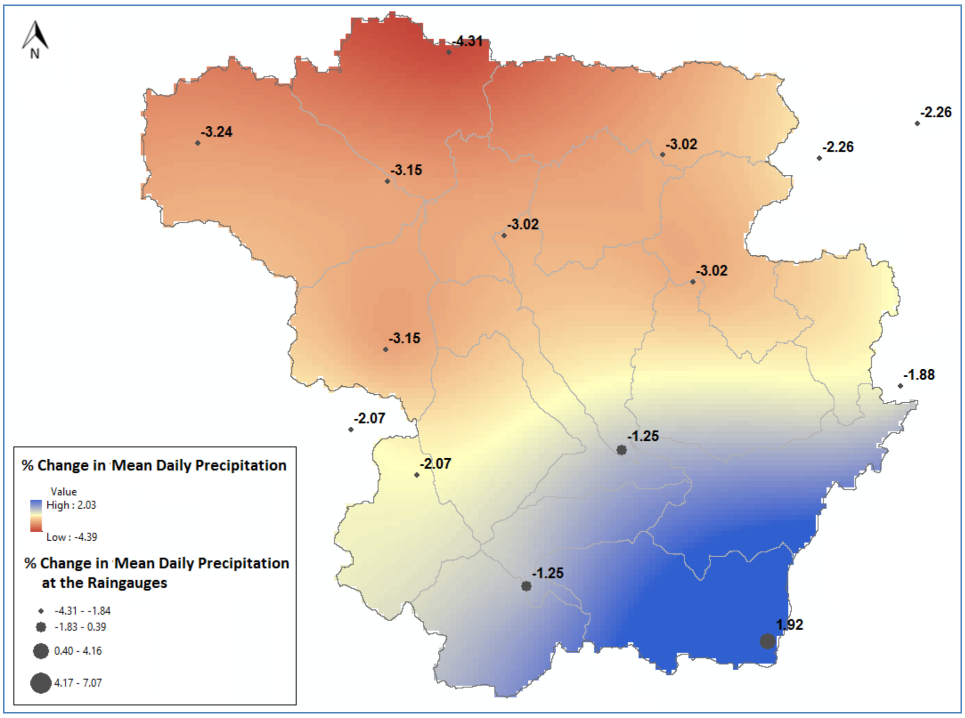


Figure 8.45: Percent (%) change in mean daily precipitation (baseline 1960-1991 vs. 2015-2030)

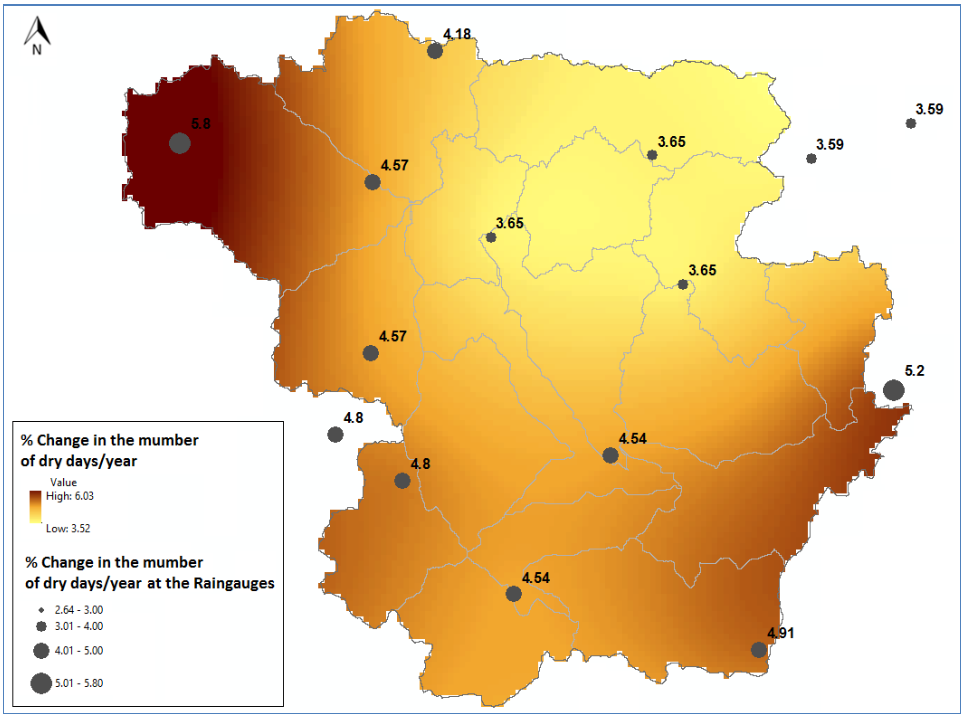


Figure 8.46: Percent (%) change in number of dry days per year (baseline 1960-1991 vs. 2015-2030)

8.8.1.2 Processing of the future climate timeseries

In order to simulate the climate change scenario (CC) in WEAP21, a post-processing of the acquired timeseries for the future years 2015-2026 has been necessary before entering the data into the WRMM. As a first step, the average daily temperature has been computed as an average of two extreme daily values (minimum, maximum). Monthly timeseries of precipitation and temperature were aggregated from the daily timeseries, using the open access timeseries analysis software Hydrognomon v.4.1.0 (.26)[3] (Kozanis et al., 2005). The period of the analysis is October 2014 to September 2026. Furthermore, the monthly timeseries were used as a basis for creating new timeseries that include the five years moving averages per month (i.e. October 2014-2018, 2015-2019 and so on). Thus, these new obtained "monthly" values of the timeseries do not represent only one single month of a specific year, but the monthly average for the next five years. In this way, it is attempted to redefine the time framework that the results of the climate model are referring to, treating the values as representative predictions around the mean value of a five year period rather than one specific year. Trend detection is also feasible in these timeseries.

The next step implemented was to compare the observed (from the raingauges) and simulated (from the climate model output) timeseries per station, for the common period 1980-2010. The comparison was performed on the interannual mean and standard deviation for each month, with the purpose to correct the simulated values if a systematic over or under-estimation was detected. This approach is commonly implemented (Loukas et al., 2004; Morrison et al., 2002; Prudhomme et al., 2002). As a result, the monthly mean value and standard deviation of temperature and precipitation have been corrected using the following equations:

$$MEAN_{correct}^{fut} = MEAN_{sim}^{fut} + (MEAN_{obs}^{hist} - MEAN_{sim}^{hist}) \quad (5)$$

$$StDev_{correct}^{fut} = StDev_{sim}^{fut} \cdot (StDev_{obs}^{hist} \div StDev_{sim}^{hist}) \quad (6)$$

Where,

MEAN = the mean value of temperature or precipitation,

StDev = the standard deviation of temperature or precipitation,

[3] Hydrognomon is a free software application for the analysis and processing of hydrological data, mainly in the form of time series. It is provided under the terms of the GNU GPLv3 License. Abailable for download at: http://hydrognomon.org/download.html

sim = index referring to the simulated values,

obs = index referring for the observed values,

hist = index referring to values of the historical period,

fut = index referring to values of the future period

correct =index referring to for the corrected values

The adjustment of future simulated time series to corrected monthly average and standard deviations was performed in two steps. Initially, a normalization of the current monthly mean values and standard deviations was performed in order to obtain the normalized variable z_{sim}^{fut}. Then, the normalized variable z_{sim}^{fut} was multiplied with the corrected standard deviation $StDev_{correct}^{fut}$ and added to the corrected mean value $MEAN_{correct}^{fut}$. The corrected timeseries of precipitation or temperature $X_{correct}^{fut}$ have been obtained using the following equation:

$$X_{correct}^{fut} = MEAN_{correct}^{fut} + (z_{sim}^{fut} \cdot StDev_{correct}^{fut}) \qquad (7)$$

The final step is the analysis of the corrected timeseries to assess their annual and seasonal trends, and further assess their impact on the potential evapotranspiration and crop water needs in the study area. These results are presented as follows.

Temperature

The average annual temperature in Trikala station for the period 2015-2026 is projected to be around 16.8 oC (+3.5% increase), versus 16.3 oC recorded during the period 1981-2001. By the end of the period it will reach the value of 17.4 oC, showing an almost linear increase after a relatively cooler period in 2018-2024 (with ~ 16.5 oC). On a seasonal basis, a temperature increase is projected during all seasons, with greater variations during winter (5-7^{o}C) and spring (15-18 ^{o}C) and a lower variability in summer (27-28 ^{o}C) and autumn (16-18 ^{o}C).

Precipitation

It is estimated that the total areal precipitation will reach 863 mm (+1.2%), compared to the 853 mm of the period 1981-2010. This value results from the spatial interpolation of rainfall across the raingauges following an elevation correction. This overall marginal increase is the leveraged output across all stations and timeperiods, and does not thus reflect the internal spatial and temporal variability across stations and seasons. More specifically, the annual precipitation in 10 raingauges is expected to increase, while it will decrease in the remaining ones (Agiofyllo, Xrysomilia, Verdikousa, Farkadona) (Figure 8.47). As a result, the mean annual precipitation will increase in 12 sub-catchments, decrease in 5, and remain about the same in 6 sub-catchments (Table 8.47). On a seasonal basis, precipitation is projected to decrease during winter and summer, and increase during spring and autumn. More specifically, precipitation increases are expected during the months of October, November, February, March May and June, while decreases are observed in December, January, April, July, August and September (Table 8.48). Substantial decrease is expected from July-September across all stations. Looking at the individual 5-year periods, we can observe that from 2015-2020 there is a decreasing trend, followed by an increasing trend in 2021-2026.

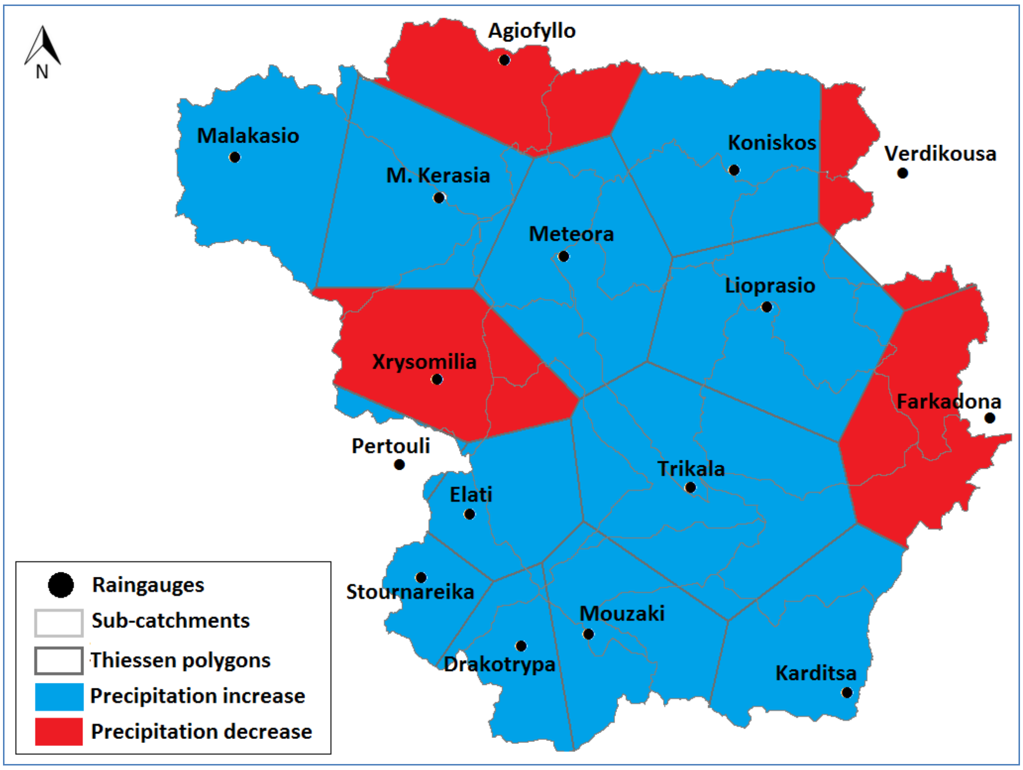


Figure 8.47: Change in mean annual precipitation from the reference period 1981-2010 to 2015-2026 per station.

Table 8.47: Mean monthly precipitation change from 1961-1990 to 2015-2026 in the Ali-Efenti subcatchments

Subcatchment	Mean Annual Precipitation	Mean Annual Precipitation	Precipitation change (%) from 1995-2010 to

	1995-2010 (mm)	2015-2026 (mm)	2015-2026
B.Koziakas	883.59	1,139.04	+29%
D.Koiti	632.20	635.43	+1%
Gavros	746.30	730.34	-2%
Ionas	878.15	880.38	0%
K. Lithaios	569.64	580.19	+2%
Klinovitis	1,332.39	1,357.78	+2%
Lithaios	443.17	428.48	-3%
Loggas	832.82	835.27	0%
Malakasio	1,186.08	1,201.54	+1%
M.Rema1	588.98	604.81	+3%
M.Rema2	583.88	607.29	+4%
Mouzaki	1,027.66	1,076.48	+5%
Neoxoritis1_Fragma	678.36	680.63	0%
Neoxoritis2	662.37	661.23	0%
Neoxoritis3	572.56	572.11	0%
N.Koziakas	771.76	801.87	+4%
Pamisos-Mesdani	654.75	677.62	+3%
Pinios-Ali Efenti	604.60	611.18	+1%
Portaikos	664.20	657.43	-1%
Pyli	1,685.11	1,703.28	+1%
Sarakina	651.40	584.37	-10%
Theopetra	571.59	542.52	-5%
Voula	616.48	619.00	0%

Table 8.48: Mean monthly precipitation change from 1961-1990 to 2015-2026

Month	Altitude corrected Areal Precipitation 2015-2026 (mm)	Precipitation change (mm) from 1981-2010 to 2015-2026	Precipation change (%) from 1981-2010 to 2015-2026
October	117	19	+19%
November	124	8	+7%
December	121	-6	-5%
January	66	-25	-27%
February	109	20	+22%
March	95	16	+20%
April	59	-13	-18%
May	61	2	+3%
June	32	4	+14%
July	25	-4	-14%
August	24	-1	-4%

September	30	-10	+25%
Annual	863	10	+1%

Evapotranspiration - Irrigation needs

The potential crop evapotranspiration is projected to rise from 1,413 mm in the period 1981-2001 to 1,446 mm (+2.3%) during the period 2015-2026, reaching about 1,473 mm at the end of the period. To calculate the evapotranspiration the Penman-Monteith methods was used assuming that all variables used in the equation maintain their reference 1981-2010 values with the exception of temperature. Evapotranspiration is expected to increase during all months, with the exception of November and January. This increase will is most prominent during the irrigation season (+2.5%). The combination of the increased crop evapotranspiration, and reduced rainfall during the irrigation season will affect incrementally the irrigation needs of the existing crops in the study area. Based on the above climatic data, it is estimated that irrigation needs of cotton would increase by 3.8%, maize by 2.7%, sugar beet by 2.7%, alfalfa by 3.3% and orchards by 3.9% (Table 8.49). If the composition of the typical acre farm in the study area remains constant, then the annual irrigation needs for the period 2015-2026 are expected to increase by 3-4%.

Table 8.49: Change in mean crop water requirements from 1961-1990 to 2015-2026

Parameter	Mean value (mm) for 2015-2026	Change (mm) from 1981-2100 to 2015-2026	Change (%) from 1981-2100 to 2015-2026
ET reference	1,446	33	+2%
Cotton water requirements	661	24	+4%
Corn water requirements	759	20	+3%
Sugarbeet water requirements	738	19	+3%
Alfalfa water requirements	978	31	+3%
Orchards water requirements	897	34	+4%

8.8.1.3 The Socio-economic scenario

The socio-economic scenario of the Ali-Efenti (CC-SE) examines potential changes and future projections of socio-economic nature up to the target year 2026, on top of the climate change projections. The CC-SE builds on the SCENES[4] "Economy First" scenario while incorporating some elements of the SCENES "Policy Rules" scenario, as downscaled and "translated" for Greece. The resulting scenario is named G1: "Confident & Competitive Greece" (Figure 8.48). The main storyline of G1 is the adoption of an open and liberal economy, with a main target to increase competitiveness and to develop comparative advantages. In this direction, all national resources are mobilized, while a "National Rehabilitation and Development Plan" is developed to draft a new national growth model with long-term targets for all sectors of the economy. The underlying assumptions of the scenario are the globalization trend, the liberalization of the markets, the balanced exploitation of fossil fuels and renewable energy, the enhancement of decision-making at the international level and the decisive influence of markets/business in policy-making. In this scenario, Greece decides to elaborate and implement a National Plan of Reconstruction and Development, which is developed with broad cooperation and consensus. The primary objectives of the plan are: productivity improvement, competitiveness rise in terms of economic efficiency and quality, innovation fostering, entrepreneurship liberalization and openness promotion. The key components of the G1 scenario storyline are to optimize the exploitation of the national natural resources (land and water resources, plant and animal capital, fish reserves, mineral and energy resources) incorporating environmental considerations, to promote competiveness and growth, to attract investments, to promote exporting, to rise the living standards and facilitate the internal domestic migration of urban population to the peri-urban and rural areas.

[4] SCENES (Water Scenarios for Europe and for Neighbouring States) is an EU funded project that developed combined qualitative and quantitative scenarios. The qualitative scenarios (storylines) provide an internally consistent picture of how water resources in different parts of Europe may develop up to 2025. The quantitative scenarios, produced by state-of-the-art models, complement the storylines by providing numerical information, and by "enriching" the qualitative scenarios by showing trends and dynamics not apparent in the storylines. http://www.peer.eu/projects/peer-flagship-projects/scenes/

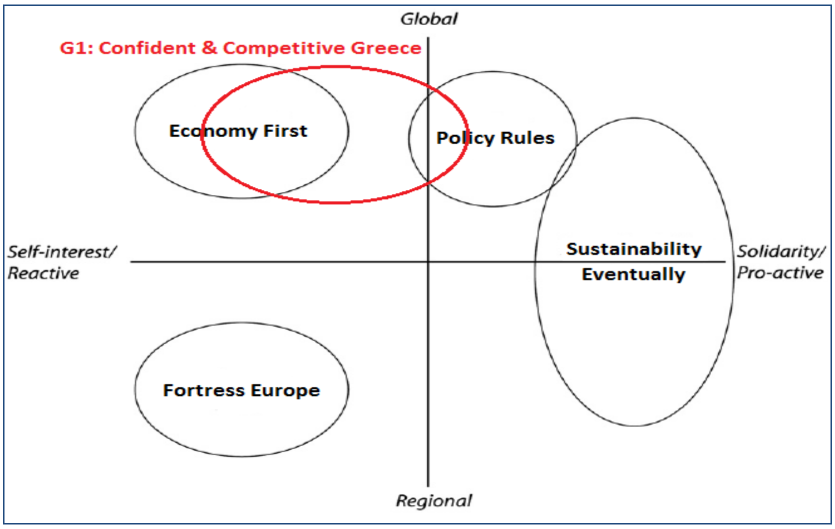


Figure 8.48: Positioning of the G1 scenario with reference to the four SCENES water scenarios

Source: modified from Kok et al., 2011

In the section below the expected impacts of the G1 storyline on the main sectors of interest are presented (Psomas, 2012). In this analysis, on top of the SCENES narratives, additional foresight studies have been reviewed and incorporated where relevant, as referenced under the sectoral impacts.

- **Impacts of the G1 scenario on the Urban sector:**

Based on the "Markets First" scenario, the population in Greece is expected to increase. Under the G1 scenario we assume that the population in the Ali-Efenti area will increase as a result of the overall population increase at the national level, as well as the internal migration from the main urban centers (Athens, Thessaloniki) to peri-urban centers (Trikala, Karditsa, etc.) (Kapa Research, 2012). The domestic per capita water consumption is expected to increase as well due to the improvement of the living conditions (also captured by the increase in the per capita GDP after 2020) and the increased temperature as induced by climate change.

- **Impacts of the G1 scenario on the Touristic sector:**

The strong promotion of Greece as a touristic resort and the boost of competitiveness will lead to an increase in the number of the foreign tourists' arrivals and number of nights spent, which are among the key drivers of water demand for tourism. The touristic sites of the area are expected to be further promoted as religion-related destinations (Meteora, Kalmbaka) and nature-related destinations (Pertouli, Plastira reservoir, Trikala). Internal tourism is also expected to increase during the autumn, winter and spring seasons. The typical water use per night spent will remain at the same levels.

- **Impacts of the G1 scenario on Land Use:**

Minor changes in land use are expected. Some increases are expected in the urban areas on the expense of grassland driven by the population and commercial/business activities increase in the peri-urban centers. The irrigated areas are expected to remain more or less constant, nevertheless land reallocation to potential high value crops (i.e. change of cultivated crops) are expected, which will also influence the irrigation water demand.

- **Impacts of the G1 scenario on the Agricultural sector:**

During the period 2015-2030 a rapid implementation and adaptation to the new Common Agricultural Policy - CAP (EC, 2012a; EC, 2012b) is undergone, with abrupt changes in the agricultural sector, in order to obtain a positive export-import balance. The production and exports are now focusing on products that have the potential to diversify in price and quality among the most competitive ones, and on products which have a greater added value than the imported ones. Attention is paid to green growth, innovation, entrepreneurship and extroversion. Young people are thus motivated to engage in the agricultural sector, bringing in new and innovative ideas and insight. A National Plan is adopted, in relation to the agricultural and livestock products, with the following main pillars:

- Selection and prioritization of the export markets to be approached (e.g. USA, France, UK, Germany, Russia, China)
- Classification of the Greek product under four main groups and adoption of a specific strategy for each group. The following groups are proposed (McKinsey & Company, 2012) (Figure 8.49):

  Export Engines: they have a positive export-import balance due to their competitive prices and superior quality against competitors (orange, peach, kiwi, grapes, seed cotton). Target: boost exports to priority markets, eliminate imports, maintain and further reduce costs.

  Emerging Traders: they have a positive or slightly negative export-import balance with significant potential to improve their competitiveness and marketable capacity (e.g. potatoes, apples). Target: reinforce exports in priority markets, eliminate imports, optimize production to further cut costs.

<u>Domestic process focused</u>: they have a marginal export-import balance (e.g. olives, tomatoes, sugarbeets), Target: Modernize and expand processing capacity, further reduce production costs to facilitate processing and import substitution.

<u>Consumption/Import majors</u>: they have significantly negative export-import balance, high domestic consumption and non-competitive prices (e.g. wheat, maize, cereals). Target: aggressively reduce local costs to reduce imports, explore selective production and land reallocation to potential high value products.

- Emphasis on alternative agricultural products with high competitive values, such as aromatic and pharmaceutical plans, superfoods, energy plants for biofuels, plants for livestock food.
- Determination of a "products' basket" for each region, with products of protected designation of origin.
- Promotion of ecological agricultural production.
- Development of a new standardization and certification mechanism of agricultural products / methods.
- Development of economies of scale, boost of production and extroversion (incentives, creation of agricultural cooperatives, etc.).
- Establishment of an institute dedicated to the promotion of Greek agricultural products.

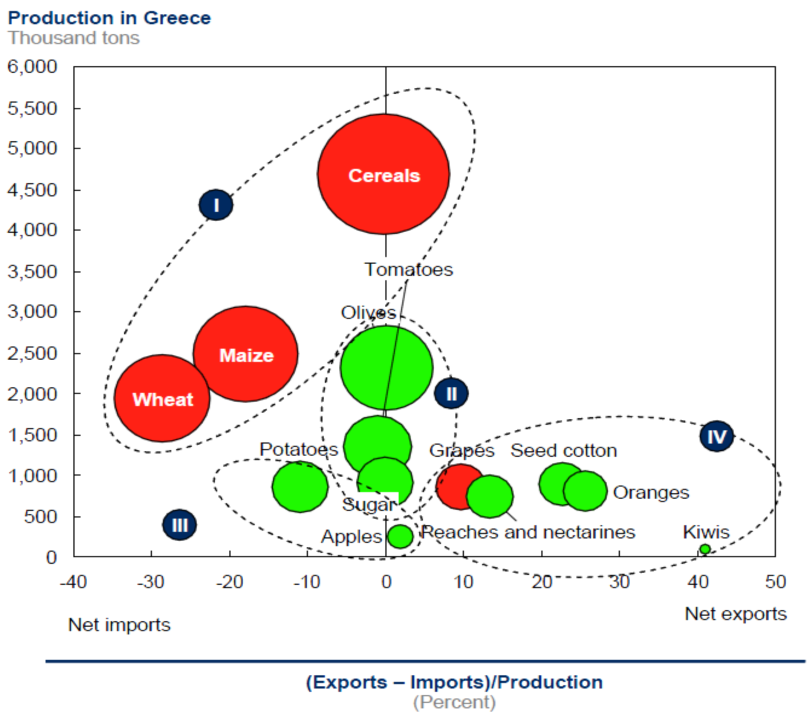


Figure 8.49: Classification of the agricultural products according to an export-import strategy

Source: McKinsey & Company, 2010

- **Impacts of the G1 scenario on the Livestock sector:**

Livestock breeding, and thus animals' population, is expected to increase as a result of the need for an increased production of meat and dairy products. Incorporating the findings of the Operational Plan of Prefecture of Thessaly "The Thessaly basket of products" (Prefecture of Thessaly, 2011) and the Report of PASEGES on the sufficiency of agricultural food products (PASEGES, 2012). In line with the latter the population of goats is expected to increase by 5-10% in order to achieve 100% self-sufficiency in goat meat and dairy products, supported as well by the new CAP. The population of cows and pigs will increase as well by approximately 15-20% driven by the need to increase the meat sufficiency by 10% (from 29% to 40%, and from 36% to 46% respectively). The population of chickens, rabbits and horses will remain at current levels, as well as the per daily water use rates per animal.

- **Impacts of the G1 scenario on the Industrial sector:**

Both the number of industrial facilities and production output are expected to increase. New facilities for the processing of agricultural and livestock products, focusing on standardization, packaging and canning are foreseen, while the existing plants are expected to expand and increase their production capacity. As such, an increase in the production output of 15-30% is expected, while the typical water use rates will remain more or less at current levels.

- **Impacts of the G1 scenario on the water-related Infrastructure:**

It is not expected that any new dams will be operational by 2030, despite the existing studies (e.g. for Mouzaki, Pyli and Neochori dams) due to legal implications with the Acheloos diversion project and the land expropriations, and the low priority of these construction works. Additional Wastewater Treatments Plants (WWTPs) will be operational by 2020, more specifically the WWTPs of Mouzaki-Mavromati, Oichalia, Megala Kalyvia and Farkadona. The existing WWTPs of Karditsa and Farkadona are also expected to expand.

The time horizon of the Ali-Efenti CC-SE scenario is 2026. The organization of the scenario is based on the sectoral water uses. More specifically, for each water use the primary factors that determine the demand are identified, and reasonable assumptions about how these factors will change in the future have been adopted. In addition there are reasonable assumptions for water related infrastructure, utilization of water resources and water treatment facilities. To quantify the socioeconomic conditions described in the G1 scenario storyline, the International Futures (IFs)[5] software v7.15 was used. IFs have already simulated the "Markets' First" scenario for Greece and the model output results are available for a wide range of parameters (Table 8.50, Figure 8.50). The G1 scenario incorporated these results, but was further refined for the Ali-Efenti basin to derive the socio-economic scenario that we applied here, focusing on the correlation between the socio-economic activities in the study area with the demand for water. Thus, an adjustment was performed on the IFs default output, incorporating the following elements and structures that are aligned with the Ali-Efenti G1 storyline: Renewable Energy Growth fast, Democracy Wave on, Investment high, Networking fast, Economic Freedom grows, Education Spending low, Health Spending low, R&D Spending high, Working Life increase, Foreign Direct Investment high, Economic Growth high, Government Effectiveness +10%, Government Corruption -5%, Agricultural Yields +10%, Agricultural Investment +10%, Aquaculture Fish Production +20%. An additional assumption was done in the CC-SE scenario concerning crop change: since this scenario is a strong economic scenario, with liberalization, free markets and driven by the driver to increase agricultural income, it is highly likely that highly marketable crops with a positive import-export balance will prevail and thus replace less profitable crops. Of course, these crops need to be compatible with the prevailing climate and soil conditions in the area. Thus, integrating the expert view of the local stakeholders about potential future swifts in the cultivated crops, it was considered that 15% of the land currently cultivated with cotton will switch to the cultivation of aloe vera. Also, 10% of the maize cultivated land will switch to cultivating kiwi, and 10% of the maize cultivated land will switch to cultivating broccoli. The resulting values (as % change from 2010) of the G1 scenario key variables, as simulated with the IFs and including the modifications described previously, are presented in Table 8.51. On this basis, the input data of the CC-SE scenario for the Ali-Efenti have been formulated and entered into the WEAP WRMM in order to perform the simulation. The input data are presented in Table 8.52, while the data entered into the WRMM regarding the new alternative crops (potential yields, producer prices, Ky) are presented in Table 8.53. As inferred from Table 8.52, the CC-SE scenario implies an increase in water demand for the

[5] The IFs software was developed at Frederick S. Pardee Center for International Futures, School of International Studies, Josef Korbel of University of Denver (http://pardee.du.edu/access-ifs). IFs v7.15 is available online (http://www.ifs.du.edu/ifs/frm_MainMenu.aspx) or for download.

domestic, livestock and industrial sector, linked to the respective increases in population and per capita water use, animal population, and industrial production. Regarding the agricultural sector, no further increase is assumed in irrigated land. Irrigation needs would only increase as a result of climate change, but would decrease as a result of cultivating less water demanding crops, so the net effect can be assessed after running this scenario in the physically based WRMM. It should be noted that scenario CC-SE does not incorporate any measures, interventions and initiatives mentioned in the G1 narrative. This is done on purpose, in order to study them separately as proposed adaptation options (ref. to section 8.6), and assess their cost-effectiveness and robustness.

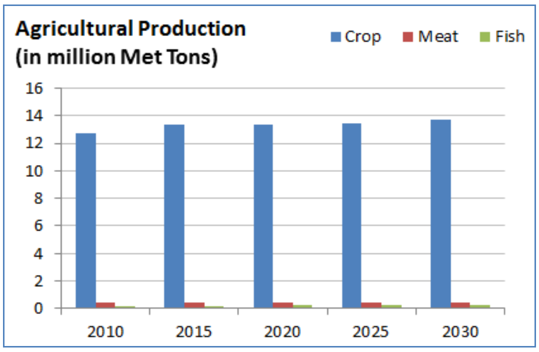
Table 8.50: Main results of the "Markets' First" scenario for Greece, as simulated with the IFs software

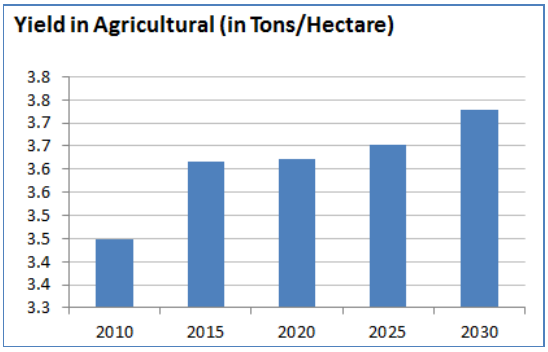
Variable Name	Values					% Change from 2010			
	2010	2015	2020	2025	2030	2015	2020	2025	2030
AGRICULTURE									
Crop - Agricultural demand - Mil Met Tons	7.67	7.50	7.38	7.27	7.09	-2%	-4%	-5%	-8%
Crop - Agricultural imports - Mil Met Tons	2.42	2.32	2.13	1.94	1.77	-4%	-12%	-20%	-27%
Crop - Agricultural production - Mil Met Tons	12.68	13.31	13.33	13.45	13.72	5%	5%	6%	8%
Crop - Agricultural exports - Mil Met Tons	2.90	3.03	3.23	3.43	3.63	4%	11%	18%	25%
Yield in agriculture - Tons/Hectare	3.45	3.62	3.62	3.65	3.73	5%	5%	6%	8%
ECONOMIC									
Private consumption - Billion $	208.90	170.20	170.50	162.90	154.40	-19%	-18%	-22%	-26%
Gross domestic product - Billion $	312.10	265.40	291.20	311.60	324.10	-15%	-7%	0%	4%
Gross domestic product at PPP - Billion $	323.80	275.10	300.60	320.50	331.30	-15%	-7%	-1%	2%
GDP per capita in 2000$ - Thousand $	28.09	23.95	26.54	28.65	30.08	-15%	-6%	2%	7%
GDP per capita at PPP in 2000$ (using 2005 ICT update from 2007) - Thousand $	29.15	24.82	27.41	29.47	30.75	-15%	-6%	1%	5%
GDP annual growth rate - Growth Rate	-4.94	2.23	1.62	1.14	0.61	145%	27%	30%	47%
Globalization level index, base years values from 0-100 (highest) - Index	28.18	38.35	44.15	47.06	47.83	36%	57%	67%	70%
Government consumption (net of transfers) - Billion $	80.04	54.41	57.72	61.67	64.11	-32%	-28%	-23%	-20%
Government expenditures - Billion $	160.60	113.50	127.70	137.70	146.70	-29%	-20%	-14%	-9%
Investment - Billion $	49.91	56.28	41.43	38.65	33.87	13%	-17%	-23%	-32%
Knowledge society index; base year 0-100 (better) - Index	35.01	28.63	31.82	34.85	37.26	-18%	-9%	0%	6%
iMports - Billion $	102.10	89.55	83.18	85.85	87.72	-12%	-19%	-16%	-14%
eXports - Billion $	75.29	74.07	104.70	134.20	159.40	-2%	39%	78%	112%
ENERGY									
Energy imports - Bil Barr OE	0.23	0.18	0.18	0.20	0.19	-21%	-20%	-13%	-16%

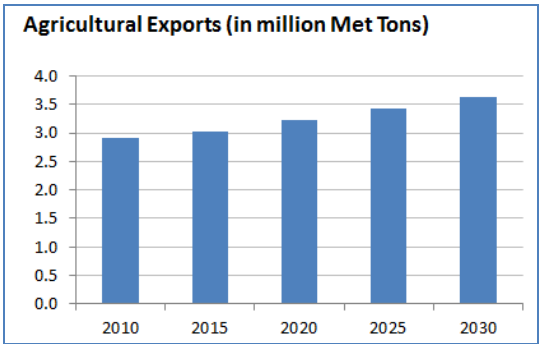
Oil - Energy production - Bil Barr OE	0.00	0.00	0.00	0.00	0.00	0%	-13%	-25%	-38%
Energy price - Base 100	100.00	128.00	128.10	127.20	148.80	28%	28%	27%	49%
Energy demand ratio to GDP - BOE/Thou $	0.71	0.73	0.69	0.67	0.64	3%	-3%	-6%	-9%
Energy exports - Bil Barr OE	0.07	0.06	0.06	0.05	0.05	-10%	-23%	-26%	-28%
ENVIRONMENT									
Annual carbon emissions from fossil fuels - Billion Tons	0.02	0.02	0.02	0.02	0.02	-13%	-15%	-19%	-21%
Forest - Land - Mil Hectares	3.90	3.94	3.98	4.02	4.06	1%	2%	3%	4%
Water usage, annual - Cubic Km	8.70	8.94	8.92	8.93	9.01	3%	2%	3%	4%
POLITICAL, DOMESTIC									
Freedom House freedom indicator (higher is more democratic;2-14;reversed from Freedom House) - Index	13.00	12.96	13.08	13.18	13.26	0%	1%	1%	2%
Government balance (deficit if negative) - Billion $	-34.20	47.03	38.18	45.81	43.61	238%	19%	-20%	5%
Unskilled - Household dividends and interest (from firms), by skill level - Billion $	3.21	1.46	1.87	1.85	1.91	-55%	-42%	-42%	-40%
Unskilled - Household social security payments to government, by skill level - Billion $	12.95	16.40	16.60	18.11	18.55	27%	28%	40%	43%
Unskilled - Household savings, by skill level - Billion $	-1.06	-19.89	-7.78	0.87	10.67	1784%	637%	-183%	-1110%
Tax rate of central government - Ratio	0.41	0.61	0.57	0.60	0.59	51%	40%	47%	46%
POLITICAL, INTERNATIONAL									
Aid (foreign), net - Billion $	-0.45	-0.39	-0.42	-0.45	-0.47	-15%	-7%	0%	4%
Power index - Index	0.35	0.25	0.22	0.20	0.17	-29%	-37%	-43%	-51%
POPULATION									
Birth - Mil People	0.11	0.10	0.09	0.09	0.09	-8%	-18%	-21%	-21%
Crude birthrate - Per Thous	10.05	9.29	8.39	8.10	8.25	-8%	-17%	-19%	-18%
Deaths - Mil People	0.12	0.13	0.13	0.13	0.13	11%	13%	12%	12%
Infant mortality rate per 1,000 live births - Per Thous	4.24	4.20	3.68	3.27	2.96	-1%	-13%	-23%	-30%
Total - Life expectancy - Years	79.84	79.89	80.56	81.20	81.78	0%	1%	2%	2%
Malnourished children as percent - Percent	1.10	1.26	1.34	1.42	1.55	15%	21%	29%	41%
Population - Mil People	11.11	11.08	10.97	10.88	10.77	0%	-1%	-2%	-3%
Population growth rate - Percent	0.04	-0.16	-0.18	-0.16	-0.16	-471%	-520%	-466%	-474%
Population in urban areas - Mil People	6.92	7.11	7.26	7.40	7.52	3%	5%	7%	9%
Population in urban areas, growth rate - Percent	0.61	0.48	0.41	0.35	0.28	-21%	-33%	-43%	-55%
SOCIAL									
Calories per capita available - Per Cap/Day	3661.00	3564.00	3562.00	3546.00	3488.00	-3%	-3%	-3%	-5%
Literacy, percentage of population, 15 and older - Percent	97.30	97.81	98.24	98.67	99.10	1%	1%	1%	2%
Total - Materialism/ postmaterialism index - Index	2.67	2.71	2.76	2.80	2.83	2%	3%	5%	6%
Physical quality of life index - Ind Max 100	96.81	96.66	96.94	97.17	97.37	0%	0%	0%	1%
Total - Survival/self-expression index - Index	0.60	0.65	0.70	0.74	0.76	8%	17%	24%	28%
Total - Traditional/Secular-	0.68	0.79	0.89	0.97	1.03	16%	30%	42%	51%

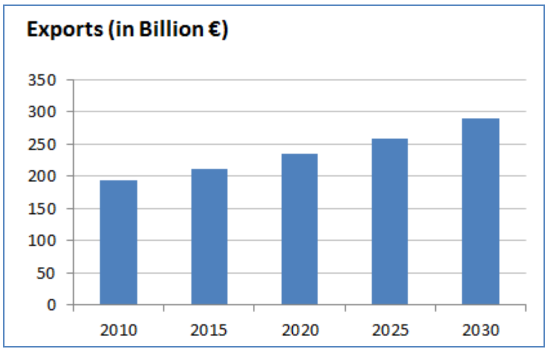
Rational index - Index		

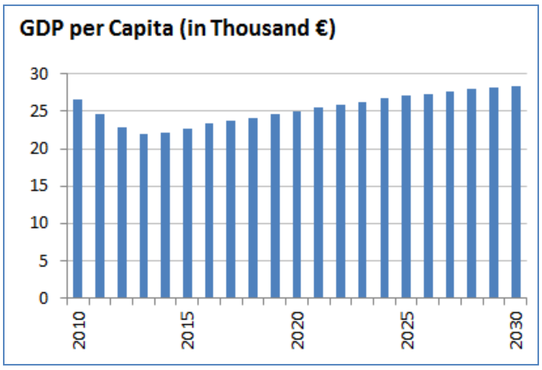
Source: http://www.ifs.du.edu/ifs/frm_Report.aspx?Country=GR

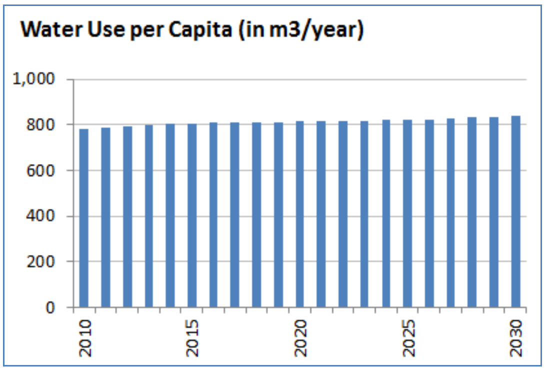


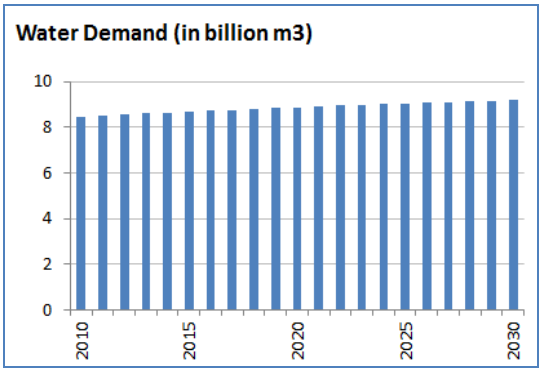


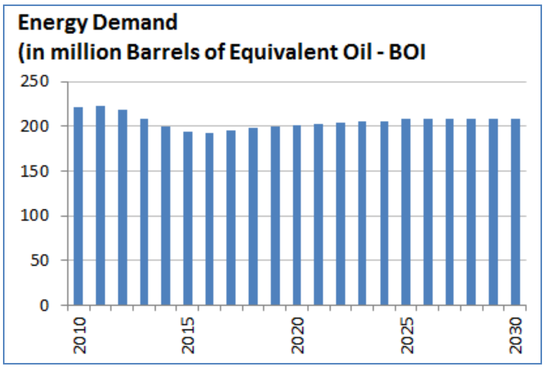












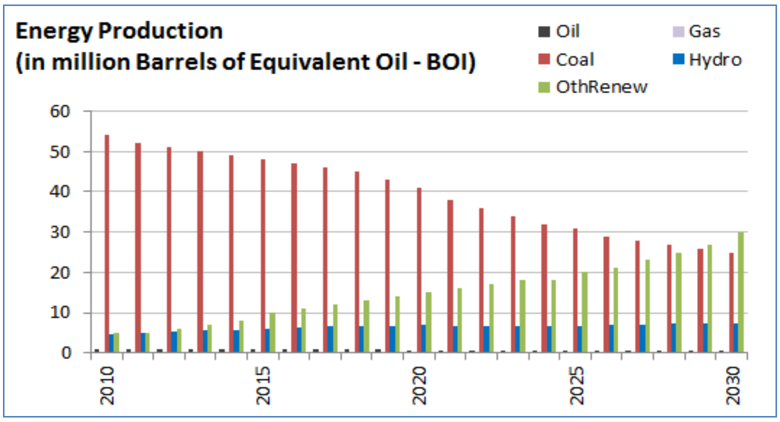


Figure 8.50: Projections of selected key variables regarding agriculture, economy, water and energy, under the "Markets' First" scenario for Greece, as simulated with the IFs software

Table 8.51: Main results of the G1 simulation with the IFs (based on the "Markets' First scenario for Greece, and incorporating the specific modifications for the Ali-Efenti)

Variable/Parameter	% Change compared to 2010	
	2020	2030
Population	1.1 %	1.4 %
Cultivated land	0.0 %	0.0 %
Grassland	-2.0 %	-3.9 %
Forests	0.3 %	0.7 %
Urban areas	0.3 %	0.7 %
Other land use	1.0 %	1.4 %
CO2 emissions	11.5 %	26.9 %
Total water use	15.6 %	25.5 %
Agricultural production	25.8 %	42.7 %
Meat production	15.0 %	25.2 %
Hydropower production	36.3 %	37.6 %
Energy production for other renewables	60.3 %	191.3 %

Source: Psomas, 2012

Table 8.52: Data input to the Ali-Efenti WRMM for the CC-SE scenario run (based on the G1 results)

Sector	Key drivers of water demand	% Change from 2010			Comments
		2015	2020	2026	
Urban	Population	2.9%	7.3%	10.6%	

	Use per capita	0%	0%	5.9%	Increase to 180 l/cap/day
Tourism	Number of nights spent	10%	20%	30%	
	Use per capita	0%	0%	0%	No change
Agriculture	Irrigated land	0%	0%	0%	No change
	Aloe vera	15%	15%	15%	15% of cotton cultivation replaced by aloe vera
	Broccoli	10%	10%	10%	10% of maize cultivation replaced by broccoli
	Kiwi	10%	10%	10%	10% of maize cultivation replaced by kiwi
	Cotton	-15%	-15%	-15%	15% reduction of cotton cultivation
	Maize	-20%	-20%	-20%	20% reduction of maize cultivation
Livestock (animal population)	Cows	0%	20%	40%	Sufficiency 40% (from 29%)
	Pigs	0%	15%	30%	Sufficiency 46% (from 36%)
	Goats	0%	5%	10%	Sufficiency 100%
	Chickens and Rabbits	0%	0%	0%	No change
	Horses	0%	0%	0%	Nonproductive animals
Land Use	Prairies	0%	-0.25%	-0.5%	
	Urban	0%	3.5%	7%	
Industry	Units of product	0%	20%	30%	

Table 8.53: Data entered into the Ali-Efenti WRMM for the new alternative crops

Crop	Potential Yield (Ym) (Kg/m^2)	Producer Price (€/Kg)	Yield response factor to water stress (Ky)*
Aloe vera	5.25	0.571	1
Broccoli	1.87	0.842	1
Kiwi	1.633	0.524	1

*Assumed equal to 1 due to lack of data. Ky=1: yield reduction is directly proportional to reduced water use.

8.8.1.4 Simulation of the scenarios in the Ali-Efenti WRMM and results

The projected climate and socio-economic changes, described in the previous sections, have been simulated in the Ali-Efenti WRMM in order to assess their impact in the study area, and evaluate their distributed effects on water demand and supply. Two future scenarios were run for this purpose, as described in Table 8.54. Scenario CC is focused solely on the future climate as a driver, while scenario CC-SE incorporates and evaluates the impact of future socio-economic changes as well.

Table 8.54: Overview of the scenarios simulated in the Ali-Efenti area

Scenario Name /ID	Simulation Period	Scenario Description
Baseline (BL)	1995-2010	Historic climate, with the existing land use, population and socio-economic characteristics of the period 1995-2010.
Climate Change (CC)	2015-2026	Projected future climate (based on A1B), maintaining the existing land use, population and socio-economic characteristics of the year 2010.
Climate and Socio-economic Change (CC-SE)	2015-2026	Projected future climate (based on A1B), with projected future land use, population and socio-economic changes (based on the G1 narrative).

The results of the CC scenario run with regard to the inflows and outflows across all subcatchments per year are presented in Figure 8.51. It is observed that the variation in the variables across the years 2015-2026 is not as high as in the previous period 1995-2010 (i.e. less variability across the years). Under the CC scenario, inflows from precipitation and irrigation are expected to increase by 1% and 7% respectively (in comparison to the 1995-2010 baseline), while outflows to evapotranspiration, surface and groundwater will increase by 4%, 1% and 0.7% respectively. Under the combined CC-SE scenario inflow from precipitation are projected to increase by 0.3%, inflow from irrigation to decrease by 3%, while all outflows are expected to decrease by about 0.2% each (Table 8.55).

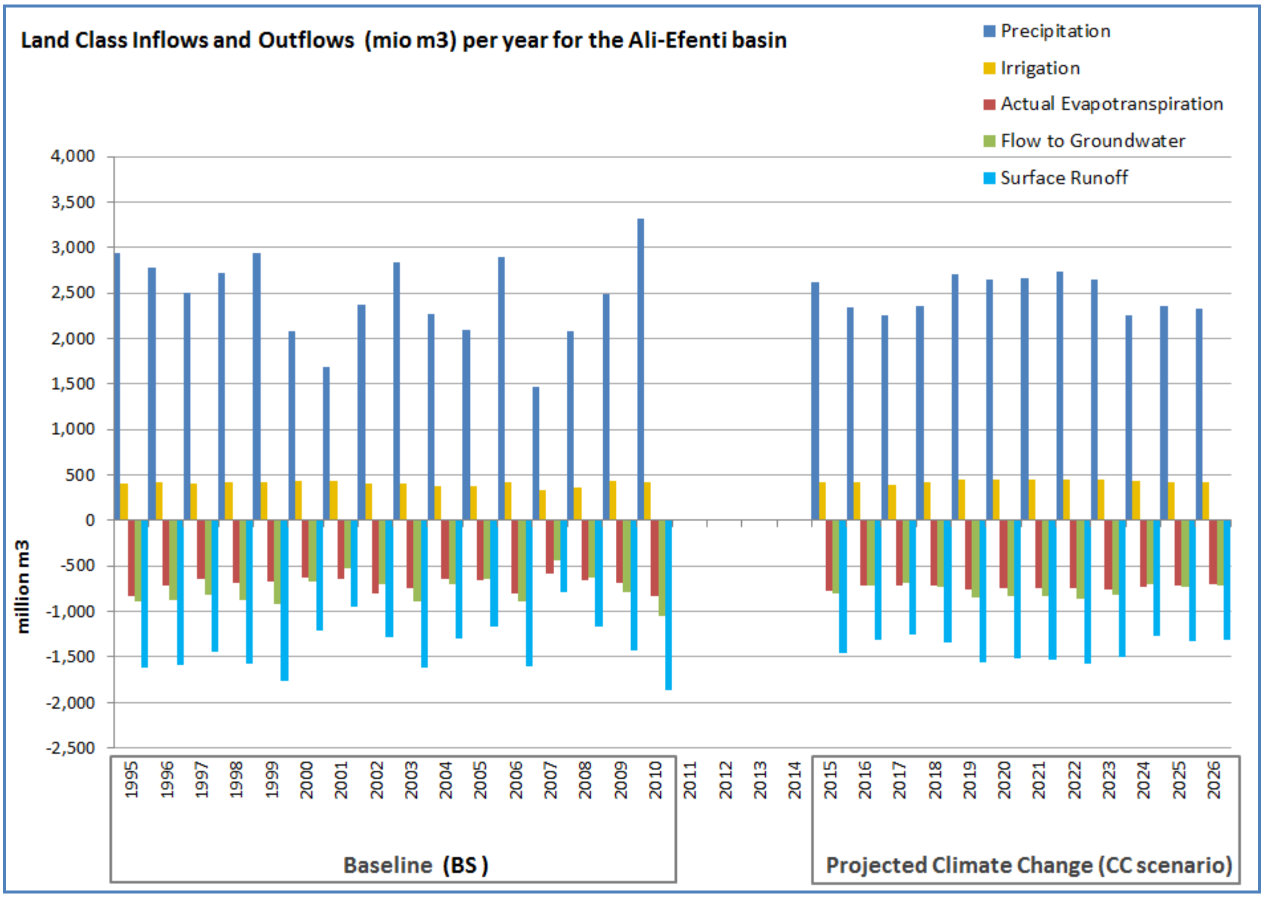


Figure 8.51: Land class inflows and outflows per year in the Ali-Efenti subcatchments from 1995-2026 (comparison across the BS and CC scenario)

Table 8.55: Mean annual inflows and outflows across all subcatchments under the different scenarios

Period/ Scenario	INFLOW (mio m3) from		OUTFLOW (mio m3) to		
	Precipitation	Irrigation	Actual Evapotranspi-ration	Flow to Groundwater	Surface Runoff
1995-2010 / BL	2,466	404	-704	-769	-1,398
2015-2026/ CC	2,491	431	-733	-775	-1,414
% change from BL	*+1.0%*	*+6.6%*	*+4.2%*	*+0.7%*	*+1.1%*
2015-2016 /CC-SE	2,474	391	-702	-767	-1,396
% change from BL	*+0.3%*	*-3.3%*	*-0.2%*	*-0.2%*	*-0.2%*

The effects of future climate and socio-economic changes on the water supply and demand are summarized in Table 8.56. Under the CC scenario the total demand is expected to increase by 2%. This is due to an increase in irrigation water demand (by 2.3%) due to the higher evapotranspiration rates. The domestic water demand is expected to decrease by 2.5% due a decrease in the population (i.e. the 2010 population used as reference for the 2015-2026 period was lower than the 1995-2010 average). The industrial and livestock water demand will remain the same (Figure 8.52). Although water demand is expected to increase, the unmet demand will decrease by roughly 3% since the potential water supply is now higher as a result of the higher precipitation. Looking into the individual sectors, the unmet demand will be thus reduced by 3% in the agriculture, 29% in the livestock, but will increase by 33% in the industrial sector which has an allocation priority 3 (Figure 8.52). With regard to the maximum unmet demand (i.e. 113.96 mio m^3 in 2007 in the BL), this was found to be significantly lower (i.e. 73.13 mio m^3 in 2017 in the CC).

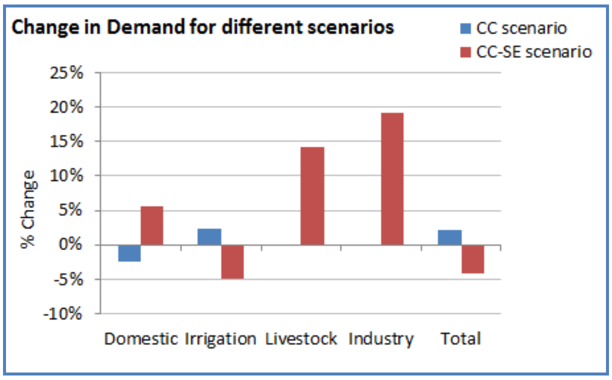
Under the CC-SE scenario the total demand is expected to decrease by 4%. This is due to the decrease in irrigation water demand (by ~5%) due to the implemented land use and irrigated crop changes. The domestic water demand is expected to increase by 5.6% due to an incremental increase in the population and daily water use rates. The industrial and livestock water demand will increase by 14% and 19% respectively due to the increase in production and animals' population Figure 8.52. The unmet demand will be significantly reduced by 46.5%, mostly attributed to the expected 46% decrease in the unmet irrigation demand. The unmet demand will also be reduced by 86% in the livestock and 56% in the industrial sectors, despite the fact that their demands have increased, since more water ("freed" from irrigation) is now available for their supply (Figure 8.52). With regard to the maximum unmet demand (i.e. 113.96 mio m^3 in 2007 in the BL), this was found to be significantly lower (i.e. 46.20 mio m^3 in 2017 in the CC).

Consequently, the percentage of water demand coverage is expected to increase under both scenarios, the CC and CC-SE, from an overall 93.52% in the BL, to 93.80% in the CC and 96.38% in the CC-SE (Table 8.56). The demand coverage will increase in all sectors, with the exception of the industrial sector under the CC scenario (slight decrease of about 1% from BL) (Figure 8.53). The individual behavior, across all scenarios, of each irrigation, livestock and industrial demand user (node) with regard to the total unmet demand is illustrated in

In these figures the unmet demand per user represents the total of the period. Since the future 2010-2026 period comprises less years than the BL 1995-2010 an extrapolation to equivalent years has been performed based on the average values. Under the CC-SE scenario the unmet demand is reduced for all livestock and industrial users (as compared to the BL), while for the irrigation users it is decreased for the vast majority with the exception of Voula and B. Koziakas subcatchments (Figure 8.54- Figure 8.56). Under the CC scenario unmet irrigation demand has decreased in 9 users (reductions range from 6% to 100%) and increased in 4 users (increases range from 3% to 77%) (Figure 8.54). Similarly, industrial unmet demand has decreased in 4 users (reductions range from 25% to 100%) and increased in 4 users (increases range from 17% to 33%) Figure 8.56, while the livestock unmet demand decreased in 6 users (reductions range from 33% to 47%) and was kept constant for the remaining ones Figure 8.55.

Table 8.56: Overview of the resulting water supply and demand per sector for the simulated scenarios

	Annual average Supply Delivered (mio m3/yr)				
	Domestic	Irrigation	Livestock	Industry	**Total**
1995-2010 BL	19.63	450.55	6.34	1.79	**478.31**
2015-2026 CC	19.14	462.40	6.37	1.77	**489.68**
2015-2026 CC-SE	20.74	442.36	7.305	2.1975	**472.60**
	Annual average Demand (mio m3/yr)				
	Domestic	Irrigation	Livestock	Industry	**Total**
1995-2010 BL	19.63	483.55	6.41	1.88	**511.47**
2015-2026 CC	19.14	494.63	6.41	1.88	**522.06**
2015-2026 CC-SE	20.74	460.04	7.32	2.24	**490.33**
	Annual average Unmet Demand (mio m3/yr)				
	Domestic	Irrigation	Livestock	Industry	**Total**
1995-2010 BL	0	33.00	0.07	0.09	**33.16**
2015-2026 CC	0	32.22	0.05	0.12	**32.39**
2015-2026 CC-SE	0	17.68	0.01	0.04	**17.73**
	Demand Coverage (%)				
	Domestic	Irrigation	Livestock	Industry	**Total**
1995-2010 BL	100.00%	93.18%	98.91%	95.21%	**93.52%**
2015-2026 CC	100.00%	93.48%	99.38%	94.15%	**93.80%**
2015-2026 CC-SE	100.00%	96.16%	99.86%	98.10%	**96.38%**



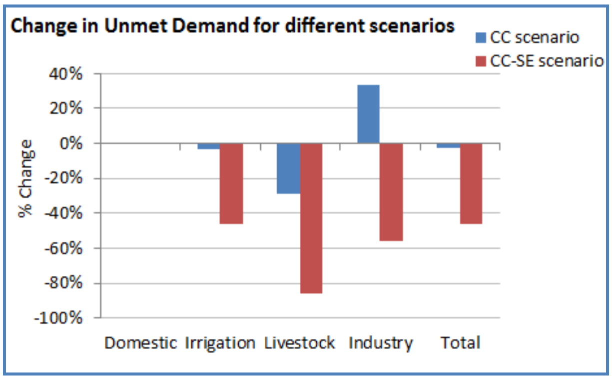


Figure 8.52: Changes in demand (left) and unmet demand (right) per sector: comparison between the BL and the CC, CC-SE scenarios

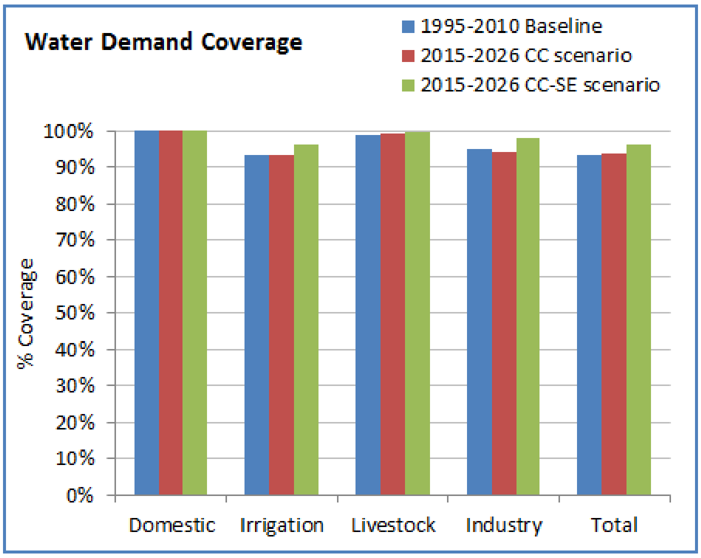


Figure 8.53: Demand coverage per sector for all scenarios

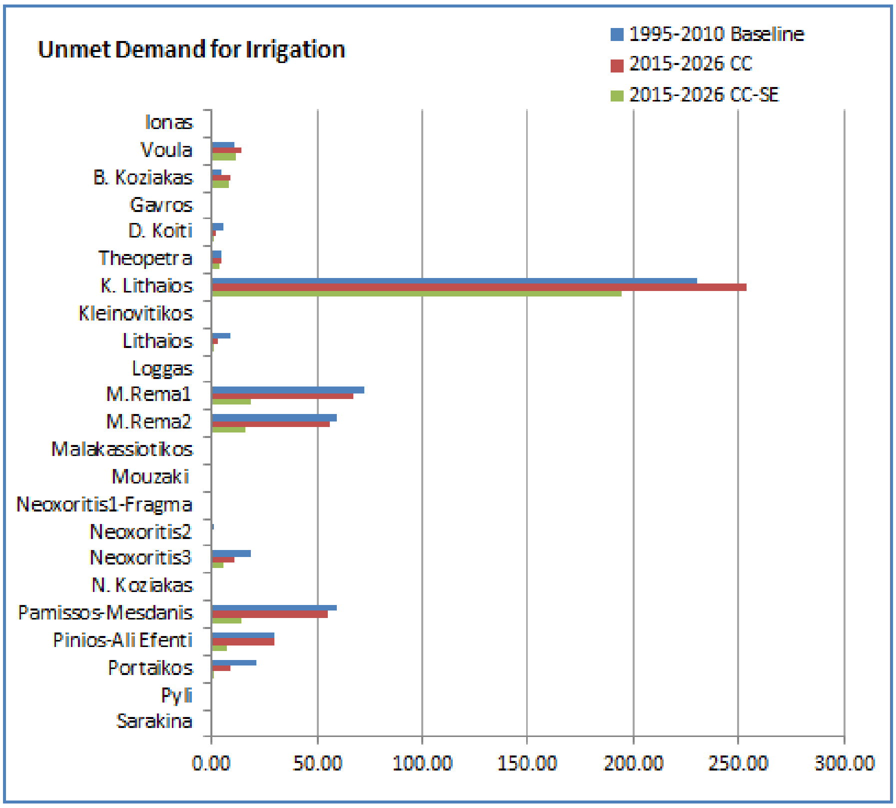


Figure 8.54: Comparison of the unmet demand for each irrigation user across all scenarios

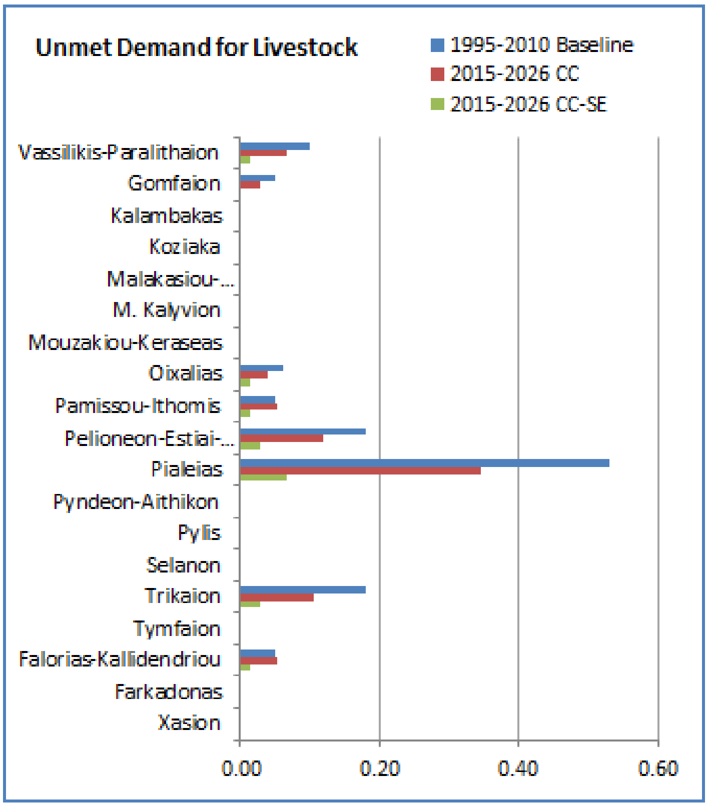


Figure 8.55: Comparison of the unmet demand for each livestock user across all scenarios

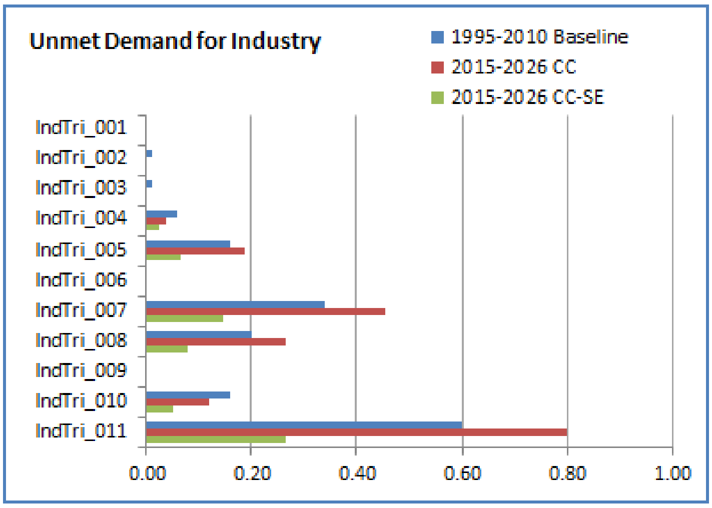


Figure 8.56: Comparison of the unmet demand for each industrial user across all scenarios

8.8.2 Robustness check and definition of indicative policy targets

In order to evaluate the robustness and the sensitivity of the solutions found during the global optimization (section 8.7), and further define indicative policy targets, twelve solutions of the optimization scenarios A and B (selected from Table 8.36 and Table 8.40) have been simulated in the WRMM under the future climate and socio-economic conditions (CC, CC-SE). The investigated solutions are presented in Table 8.57, and have been chosen on the basis of representativity and expert judgment. Solution No.0 represents the baseline of not applying any measures (business as usual –BaU). The unmet demand in the case is 113.96 mio m3 and it refers to the value observed during the dry year 2007. Solutions No.2 and No.3 are expected to deliver reductions in unmet demand around 20% and 30% under the BL scenario, and have similar costs under both scenarios. Solution No.5 is expected to deliver a reduction in unmet demand around 50% in the BL, but the delivery of this saving requires a slightly higher cost under scenario A. Solutions No.6 and No.7 are expected to deliver reductions in unmet demand around 70% and 80% under the BL scenario, but the delivery of this savings requires a significantly higher cost under scenario A (more than double) since more than 10% DeffIrr is applied under scenario B. Finally, Solutions No.6 and No.7 are expected to deliver reductions in unmet demand around 100% and 130% under the BL scenario, practically eliminating the unmet demand, and are feasible only under scenario B. The parameters modified in the WRMM in order to simulate these solutions under CC and CC-SE scenarios are the Wmu, the Irrigation Efficiency Coefficients of Karditsa and Trikala, and the deficit irrigation (DefIrr), as also described previously.

Table 8.57: Selected solutions for robustness check under the CC and CC-SE scenarios

Solution #	% Reduction in Unmet Demand *	Optimization Scenario	Investment cost (AEC) (mio €)	% Increase WSu	% Increase in Karditsa Irrigation Efficiency	% Increase in Trikala Irrigation Efficiency	% Deficit Irrigation
2A	~ 20%	A	2.07	2.03%	9.07%	3.21%	-
2B		B	2.08	7.29%	8.57%	0.58%	1.34%
3A	~ 30%	A	3.63	9.41%	10.15%	6.79%	-
3B		B	3.59	10.24%	2.43%	7.31%	2.90%
5A	~ 50%	A	7.69	11.52%	17.64%	10.27%	-
5B		B	4.58	13.50%	11.5%	3.3%	5.20%
7A	~ 70%	A	12.8	2.04%	25.66%	16.28%	-
7B		B	6.77	3.66%	12.3%	3.3%	11.07%
8A	~ 80%	A	17.75	35.27%	28.90%	17.00%	-
8B		B	7.33	7.13%	10.09%	2.60%	14.16%
10A	~ 100%	A	-	-	-	-	-
10B		B	9.27	0.90%	6.94%	2.90%	21.51%
12A	~ 130%	A	-	-	-	-	-

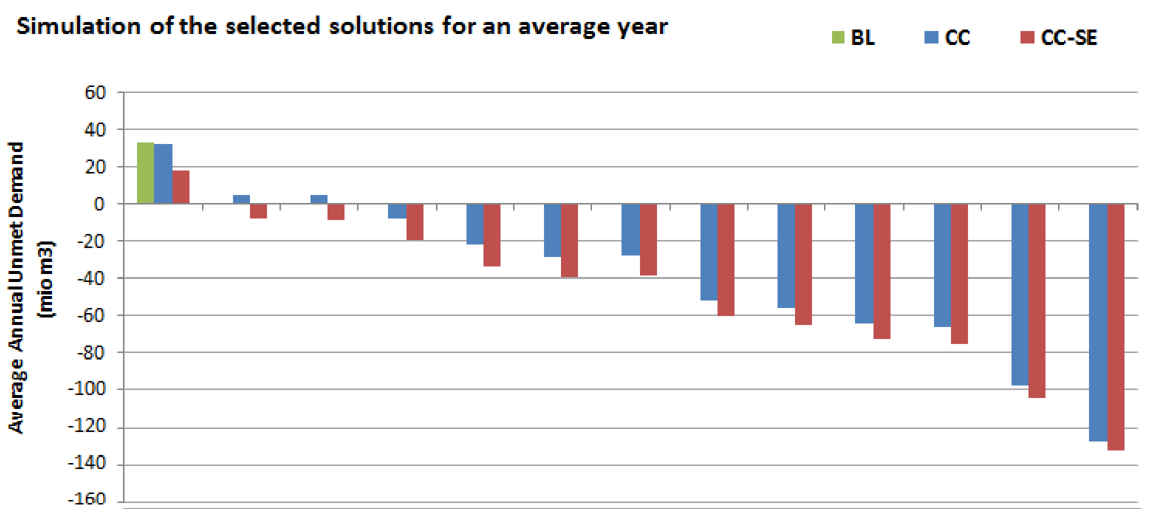
12B		B	11.69	3.42%	6.75%	2.33%	27.77%

* this percentage refers to the unmet demand of the year 2007 (i.e. 113.96 mio m^3)

The results of the simulations, for both the CC and CC-SE scenarios are presented in Figure 8.57 for average conditions and in Figure 8.58 for the driest year (i.e. 2007 in the BL, and 2017 in the CC and CC-SE scenarios). The solutions were found to be robust in all cases, and deliver the expected savings. The solutions of scenario B result in greater savings (due of course to the deficit irrigation as previously discussed). Ranking of the solutions in terms of savings delivered (and resulting reduction in unmet demand), results in the following order:

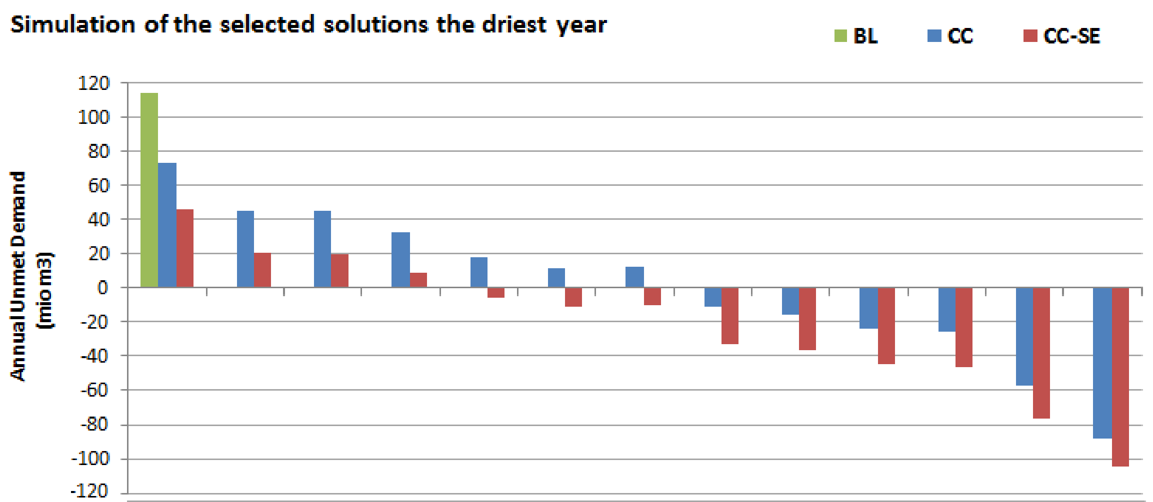
12B > 10B > 8B > 8A > 7B > 7A > 5A> 5B > 3B > 3A > 2B > 2A

For average conditions, all solutions beyond the 2B (i.e. 3A to 12B) result in a total elimination of unmet demand and start delivering water surpluses. For the driest year (i.e. representing the most conservative case), this is achieved by all solutions beyond 5B (i.e. 7a to 12B). The specific measures that need to be implemented for each solution, are “translated” from the intervention curves. For scenario B these are presented in Table 8.58 (a full list of penetration of each measure based on the intervention curves is provided in Annex 3).



Solutions	0	2A	2B	3A	3B	5A	5B	7A	7B	8A	8B	10B	12B
BL	33.16												
CC	32.39	4.91	4.69	-7.65	-22.14	-28.79	-27.57	-51.70	-55.76	-63.98	-66.22	-97.63	-127.85
CC-SE	17.73	-7.81	-8.20	-19.73	-36.69	-39.42	-38.55	-60.44	-64.78	-72.82	-74.75	-104.20	-132.66

Figure 8.57: Results of the simulated selected solutions for an average year



Solutions	0	2A	2B	3A	3B	5A	5B	7A	7B	8A	8B	10B	12B
BL	113.96												
CC	73.15	45.51	45.30	32.90	18.19	11.64	12.88	-11.42	-15.48	-23.73	-25.99	-57.57	-87.95
CC-SE	46.19	20.54	20.21	8.61	-5.36	-11.16	-10.20	-32.37	-36.55	-44.55	-46.49	-76.03	-104.52

Figure 8.58: Results of the simulated selected solutions for the driest year

Table 8.58: Translation of the scenario B solutions on the basis of the intervention curves

			SOLUTIONS:	0	2B	3B	5B	7B	8B	10B	12B
Urban Measures	WC			-	36%	50%	66%	16%	35%	3%	15%
	shower head			-	-	-	-	-	-	3%	-
	faucet			-	-	-	-	-	-	-	-
	washing machine			-	-	-	-	-	-	-	-
	dishwasher			-	-	-	-	-	-	-	-
	RWH			-	-	-	-	-	-	-	-
	GWR			-	-	-	-	-	-	-	-
Agricultural Measures	Karditsa (hectares under each practice)	Collective Networks - Closed pipes	Furrow	0	1	1	4	4	4	2	1
			Sprinkler	600	646	605	660	661	656	625	634
			Drip	386	606	397	920	926	883	454	847
			Drip -PA	0	292	1	784	783	358	79	173
		Collective Networks - Open pipes	Furrow	686	475	674	117	112	163	617	197
			Sprinkler	2,101	205	1,388	150	146	167	345	235
			Drip	515	2,356	1,224	2437	2,439	2416	2,246	2,373
		Individual Networks - Closed pipes	Sprinkler	15,970	15,780	15,960	15,527	15,108	15,913	15,935	15,918
			Drip	161	351	171	604	1,023	218	196	213
			Drip -PA	0	180	17	571	965	141	87	63
	(hectares under each	Collective Networks - Closed pipes	Furrow	0	1	6	3	3	3	3	2
			Sprinkler	8,578	8,573	8,426	8,522	8,522	8,541	8,518	8,532
			Drip	1,430	1,460	1,760	1,617	1,617	1,551	1,649	1550
			Drip -PA	0	109	1,657	1,013	1,013	291	843	644

Collective Networks - Open pipes	Furrow	204	153	8	57	57	98	22	102
	Sprinkler	0	25	8	11	11	18	17	24
	Drip	0	1	3	2	2	2	2	2
Individual Networks - Closed pipes	Sprinkler	13,563	13,555	10,670	13,512	13,512	13,529	13,539	13,513
	Drip	3,825	3,834	6,718	3,877	3,877	3,859	3,849	3,875
	Drip –PA	0	577	6,647	3,432	3,432	3,170	3,198	2,693
Deficit Irrigation (%)		0.00%	1.34%	2.90%	5.20%	11.07%	14.16%	21.51%	27.77%

In order to define indicative policy target, decision-makers need to also consider, additionally to the water saved and total cost of each solution, the breakdown of costs per sector (urban vs. agriculture) (Figure 8.59), the breakdown of costs within the agricultural sector (i.e. investment cost for improving efficiency vs. loss of farmers' income associated with deficit irrigation) (Figure 8.60), as well as the unit cost for each m^3 saved (€/m^3) (Figure 8.59). Another consideration is whether the targets are focused to alleviate average or extreme conditions; the latter are more conservative. Looking at the breakdown of costs per sector (Figure 8.59), it is apparent that the share of agricultural costs is much higher than the urban. In solution No. 8A, the urban costs are relatively high (as compared to those of other solutions) and result in disproportionally increasing the total cost. This is due to the fact that urban water savings are emphasized, and in order to reach the desired 35% of this solution a quasi-full penetration of WC, showerheads, and faucets is required (95%, 100% and 85% respectively). As this solution does not render any better savings than others despite its high cost, it is considered as non-cost-effective compared to others. Solutions 10B and 12B, although they deliver the greatest savings at a relative low unit cost (about 0.07€/m^3), they are over-performing one hand (i.e. the need for such large savings is not substantiated), while the costs burden almost entirely (85%) the farmers. This is due to the fact that these solutions apply high levels of deficit irrigation (>20% deficit irrigation). Thus, they are also considered as non-fit-for-purpose.

Solution 5B is probably the most equitable solution: it eliminates unmet demand under average conditions, and even generates a surplus of about 30 mio m^3, and can also accommodate extreme conditions (only 12 mio m^3 of unmet demand under the CC, while a surplus of 10 mio m^3 under the CC-SE), with a low unit cost of 0.07 €/m^3 saved. At the same time is has a relatively fair cost contribution from both sectors (11% urban and 89% agriculture), and most importantly, a fair distribution of the agricultural costs (56% investment cost, 44% lost farmer' income).

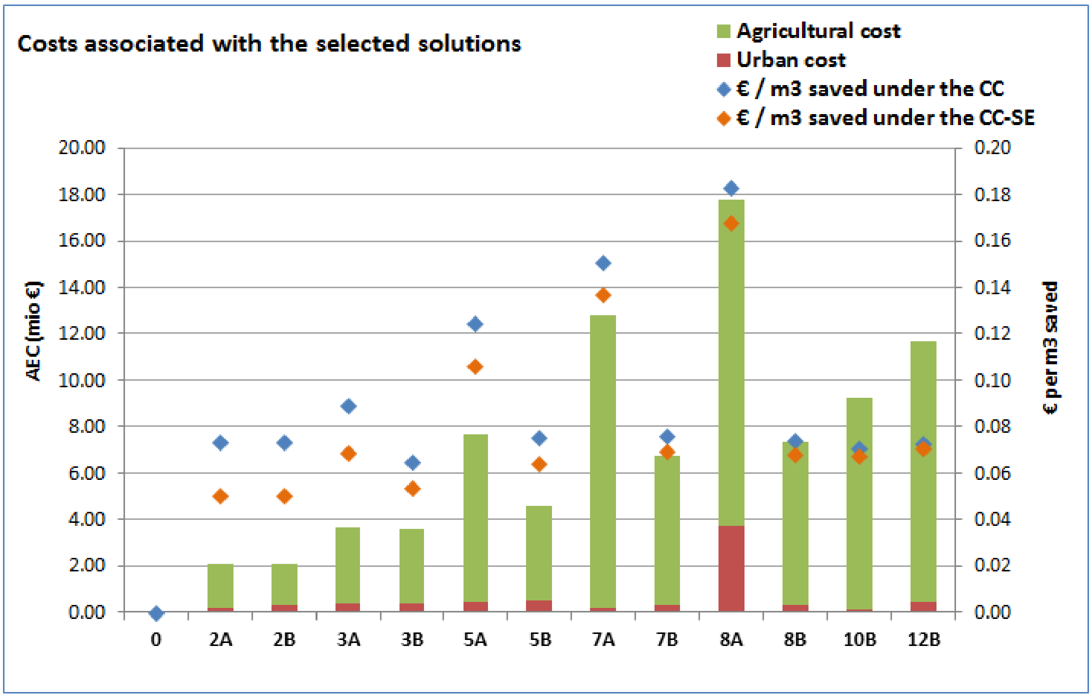


Figure 8.59: Breakdown of costs between sectors for the selected solutions, and associated unit costs under the CC and CC-SE scenarios

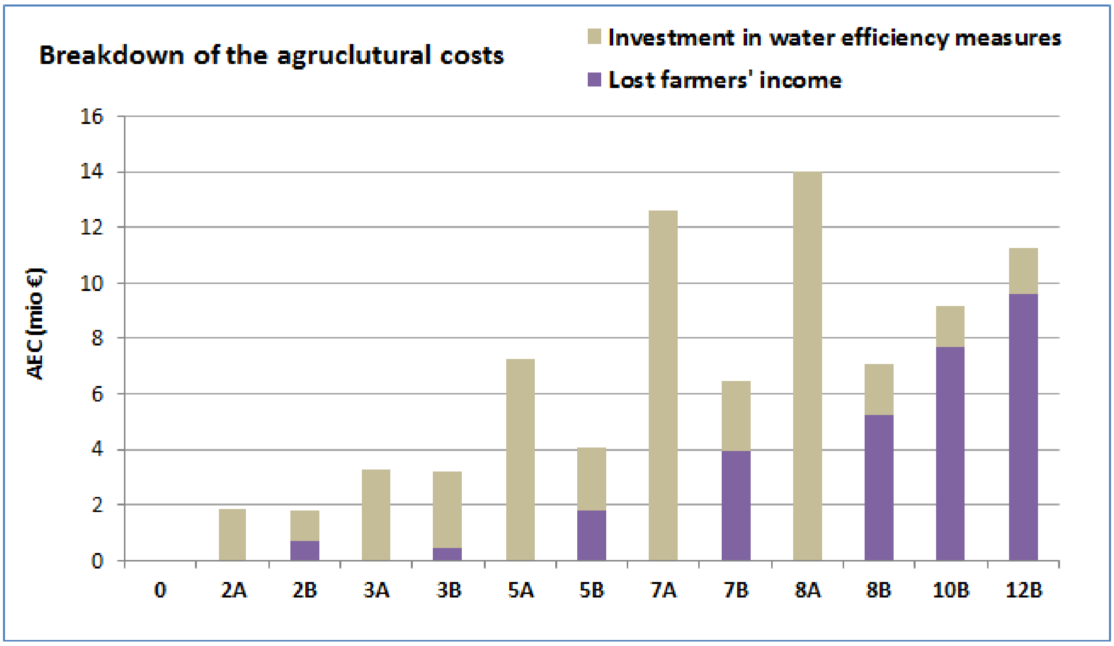


Figure 8.60: Breakdown of the agricultural costs

As it is observed, the different solutions fit different purposes, each one with each one advantages and disadvantages. Which solution(s) will be finally selected in order to define relevant targets is subject to the policy goals to be achieved. This decision-making process needs to implement a multi-stakeholder participatory approach, so that the goals to be achieved are defined within a rational and publicly accepted reasoning, and the subsequently defined targets can serve these goals. Table 8.59 illustrates some example goals and relates them to the selected solutions, setting of this basis appropriate targets and accompanying actions.

Table 8.59: Indicative policy goals, resulting targets, and supporting actions

Goal	Lowest possible unit cost, with a maximum AEC of 7 mio m^3
Rationale behind the goal	Limited financial Resources
Adequate Solutions	3B (and 2A, 2B)
Policy Targets	▪ Achieve urban water saving of 10% ▪ Increase the irrigation efficiency of Karditsa by 2.4% (achieve an efficiency of 77.23%) ▪ Increase the irrigation efficiency of Trikala by 7.3% (achieve an efficiency of 83.27%) ▪ Apply 3% deficit irrigation
Specific Actions	▪ Install efficient WCs in 50% of the households ▪ In Karditsa: Convert 718 ha from sprinkler to drip, 12 ha from furrow to drip; Apply PA to 18 ha; Convert 16 ha from open channels to closed pipes ▪ In Trikala: Convert 3,037 ha from sprinkler to drip, 190 ha from furrow to drip; Apply PA to 8,304 ha; Convert 185 ha from open channels to closed pipes ▪ Apply 3% deficit irrigation

Goal	Eliminating unmet demand in all cases, and without burdening the farmers, at the lowest possible cost
Rationale behind the goal	Maximize societal welfare
Adequate Solutions	7A
Policy Targets	▪ Achieve urban water saving of 2% ▪ Increase the irrigation efficiency of Karditsa by 26% (achieve an efficiency of 94.75%) ▪ Increase the irrigation efficiency of Trikala by 16% (achieve an efficiency of 90.23%)
Specific Actions	▪ Install efficient WCs in 6% of the households, and showerheads in 8% of the households ▪ In Karditsa: Convert 11,765 ha from sprinkler to drip, 576 ha from furrow to drip; Apply PA to 10,827 ha; Convert 610 ha from open channels to closed pipes ▪ In Trikala: Convert 11,395 ha from sprinkler to drip, 190 ha from furrow to drip; Apply PA to 16,695 ha; Convert 185 ha from open channels to closed pipes

Goal	Eliminate unmet demand in average conditions, with and investment cost of less than 7 mio m^3 AEC, and assuming an equal share of the agricultural cost among the government (investments) and the farmers (loss of income)
Rationale behind the goal	Sharing of the financial burden with beneficiaries, budgetary constraints

Adequate Solutions	5B (and 7B as second option)
Policy Targets	▪ Achieve urban water saving of 13.5% ▪ Increase the irrigation efficiency of Karditsa by 11.5% (achieve an efficiency of 84.08%) ▪ Increase the irrigation efficiency of Trikala by 3.3% (achieve an efficiency of 80.17%) ▪ Apply 5% deficit irrigation
Specific Actions	▪ Install efficient WCs in 66% of the households ▪ In Karditsa: Convert 2,334 ha from sprinkler to drip, 565 ha from furrow to drip; Apply PA to 1,355 ha; Convert 598 ha from open channels to closed pipes ▪ In Trikala: Convert 96 ha from sprinkler to drip, 144 ha from furrow to drip; Apply PA to 4,445 ha; Convert 134 ha from open channels to closed pipes ▪ Apply 5% deficit irrigation

Goal	Maximize the water savings from the urban sector
Rationale behind the goal	Minimize the risk of non-performance of the agricultural measures. due to week enforcement at the farm level (illegal abstractions)
Adequate Solutions	n/a (the only solution that partially fits is 8A) Comment: in this case the optimization problem was not defined correctly. The solutions should have excluded irrigation measure and only focus on urban. Best-fit solutions is this case can be obtained from the urban intervention curve and tested for their robustness under CC and CC-SE
Policy Targets	▪ Achieve urban water saving of 35% (based on 8A)
Specific Actions	▪ Install efficient WCs in 95% of the households, showerhead in 100% of the households, and faucets in 85% of the households (based on 8A)

8.9 Concluding Remarks

8.9.1 Summary of conclusions

The methodological approach has been validated in the Ali-Efenti catchment of Pinios River Basin, in Thessaly. The area has extensive agricultural activities, with the main irrigated crops being cotton (44% of the agricultural land), maize, alfalfa and sugarbeets. The main water user is irrigation. The mean annual water demand reaches approximately 500 mio m^3, of which 94.5% are irrigation water demands, 3.8% domestic (including touristic), 1.3% livestock, and 0.4% industrial. The catchment is prone to drought hazards, while the imbalance between water availability and demand creates water stress problems.

- **Conclusions on the Water Resources Management Modeling:**

To obtain a good representation of the physical system of the Ali-Efenti, and the interactions between natural and anthropogenic drivers, impacts and pressures, a detailed Water Resources Management Model (WRMM) has been developed, using the WEAP21 software. Results of the model (i.e. the unmet demand per user and sector) are necessary to feed the drought vulnerability and risk analysis, while the WRMM is also used as the "simulation engine" in the process of selecting optimum bundles of demand management interventions and defining policy targets. The WRMM is node-based with a monthly resolution, calibrated and validated for the period 1980-1994, while a baseline (reference) has been developed for the period 1995-2010. The WRMM has been proved able to represent in great details both the salient features of the hydrological cycle as well and the various demand and water supply functions per sector. The average annual unmet demand of the baseline 1995-2010 is estimated to be 33.16 mio m^3, attributed almost entirety to irrigation, with some minor percentages attributed to livestock and industry (0.2% and 0.3% respectively). Demand coverage ranges across sectors: 100% for domestic (priority 1), 93% for agriculture and 99% for livestock (priorities 2), and 95% for industry (priority 3). The worst year (in terms of precipitation and drought) was 2007, and the resulting unmet demand reached 114 mio m^3. That year, demand coverages were 100%, 77%, 94% and 77% for the domestic, agricultural, livestock and industry sectors respectively.

- **Conclusions on the Drought Hazard Analysis:**

The drought hazard in the catchment has been analyzed for the 30-year period 1980-2010, based on the **Drought Hazard Indicator (DHI)**. The DHI has been calculated in 17 rain gauges within the basin, and spatially interpolated across these stations. It has also been calculated for the sub-periods 1981-1995 and 1995-2010 to allow for the understanding of the drought hazard evolution. The analysis revealed that drought events are frequent in the area, and commonalities, in terms of drought occurrence, exits across the stations, with the main drought events noticed during the years 1988-90, 1992-94, 2000-02 and 2007-08. Overall, it can be observed that the event with the largest drought magnitude across the observation gauges has been experienced within the period 1981-1995, while the event with the largest duration has been experienced within the period 1996-2010. With regard to the prolonged events, with durations of more than 60 months, these are experienced in few locations and are more apparent during the recent period 2004-2010. Comparing across the sub-period 1981-1995 and 1996-2010, we can observe that the number and the maximum magnitudes of the drought events decrease in the second period, yet their durations tend to increase. We can thus conclude that the occurrence of drought episodes may be a bit less frequent and/or intense in terms of magnitude, but they are now longer, and can evolve into prolonged drought of more than 60 months duration. Zones of higher to lower exposure alternate from north to south, in an east-west orientation. The zones with the highest DHI (2.00-3.16) prevail in the northern area and the south, while a lower risk zone lies in the center. When comparing the two sub-periods we can observe that the average DHI value across all stations has been slightly reduced by 6% during the second period, yet the maximum observe value in 10% higher. While in the period 1981-1995 the drought hazard was more significant in the northern part of the catchment (DHI > 2) it has now "migrated" to the southern part. Thus, the southeast of the catchment clearly experiences an increased exposure to the drought hazard, while in the north a decreasing trend can be observed. Unfortunately, the area where the DHI has increased coincides with the main irrigation districts of the catchment where a lot of the water is needed for agricultural purposes, thus making them prone to increased water stress conditions.

- **Conclusions on the Drought Vulnerability analysis:**

The analysis of the vulnerability in the Ali-Efenti has been based on the Drought Vulnerability Index (DVI). The DVI has been derived and mapped at the sub-catchment level (for 17 sub-catchments within the basin), for all three reference periods (1981-2010, 1981-1995, 1996-2010). Out of the 17 sub-catchments, 29% are classified in class 3 (high vulnerability), 24% in class 2 (moderate), and the reaming 47%are in class 1 (low vulnerability) when analyzing the entire period 1981-2010. Looking at the two sub-periods individually (1981-1995 and 1996-2010) we can observe an overall increase in vulnerability across the catchments. Overall, the average increase in vulnerability across the two sub-periods is around 0.37 which basically represents 37% of a class span, in other words an average increase of about 1/3rd of a class is observed. Looking at the spatial distribution, it is observed that the south-eastern part of the Ali-Efenti is most vulnerable (medium to high degree of vulnerability) to drought during the period 1981-2010. The analysis of the two individual sub-periods shows an increase in the vulnerability of the southern part of the basin, namely in the Mesdani, Ali-Efenti, Ali-Efenti1, and Pamissos sub-catchments, during the latest period.

- **Conclusions of the Drought Risk analysis:**

The Drought Risk Profile (DRP) of the Ali-Efenti basin, has been based of the Drought Hazard Index (DRI), which is derived by multiplying the DHI and DVI. Overall, a moderate drought risk is observed in the northern part of the Ali-Efenti and in some parts of the central area of the basin for the period 1981-2010. High risk is observed in the south-eastern part of the Ali-Efenti, with the sub-catchments of Lithaios, Mesdani, Neoxoritis, Ali-Efenti, Ali-Efenti 1, and Ali-Efenti 2 being exposed. Pyli (in the south-western) also experiences a moderate drought risk. In the very center, a small area of the Ali-Efenti demonstrates a very high risk. Analyzing the evolution of risk across the two sub-periods, we can observe a shift of the risk areas towards the southern part of the basin: the northern part of the basin is becoming less prone to drought (risk classes decline from moderate to low), while the south-eastern part becomes more prone (risk classes increase from low to high). The highest increases in the DRI are observed in the Mesdani, Ali-Efenti and Ali-Efenti sub-catchments, where the main irrigated areas are located.

- **Conclusion on the interventions curves' simulation:**

In order to simulate the impact of different measures in the urban and agricultural sectors, intervention curves have been developed and simulated in the WEAP21 WRMM in order to assess the impacts on the physical system.

The measures for the **domestic sector** included: installation of dual flush toilets (1), retrofitting of low flow taps (2) and showerheads (3), installation of efficient washing machines (4) and dishwashers (5), istallation of rainwater harvesting (6) and domestic greywater reuse (7) systems. The daily water use was assumed to be 170lt/cap/day. Based on this measures, the total potential water saving, if applying all tier 1 measures (i.e. creating a "water efficient house" with measures 1-5), is estimated to reach 46.5% of the total household consumption. The application of additional tier 2 measures (i.e. rainwater harvesting-RWH, greywater reuse-GWR) on top of the tier 1 measures delivers an additional 16.2% saving, thus a total of 62.7% domestic water saving potential. To simulate the urban intervention curve in the WRMM, a user defined variable "Wmu" has been introduced, which represents the percentage of water saved by applying the bundle of urban water saving measures of the intervention curve. The results of the model simulation depict the variability in water savings among the different demand nodes. The Business as Usual (BaU) represents the current situation, thus no measures are adopted, water saving is 0%, and the unmet demand remains at current levels (0.36 mio m^3 for the dry year 2007). With a very low cost of less than 5 € AEC/hh, a rough 8% saving of the urban water use can be achieved. This solution requires the installation of low-flow showerheads in 38% of the households in the Ali-Efenti. With an AEC of 53 €/hh, 34% of water can be saved (i.e. cost of 0.54 €/m^3 of water saved). This requires the quasi-full penetration of low-flow showerheads and dual flush toilets (91%), and further introduces low-flow taps (2 items per hh) in 70% of the households. To further save water beyond the level of 37%, additional tier 1 measures (on top of the dual flush toilets, low-flow showerheads and taps) are gradually required, i.e. efficient washing machines followed by dishwashers, starting for a degree of penetration of 9% and gradually increasing. Two interesting solutions are observed at the range of 43% water saving, with an AEC of about 200 €/hh. These solutions require a unit cost of about 1.4 €/m^3 which is close to the average cost of water in the area. In this case RWH systems are introduced in 9% of the households while the penetration of dishwashers is restricted to either 0% or 16%. Above the level of 45.5% saving the unit cost of water saved is more than 2.1 €/m^3 and thus relatively expensive. In general, beyond the level of 37% saving target, the equivalent unit cost in €/m^3 of water saved fluctuates within the boundaries of the total cost of water in the area (0.68 €/m^3 - 2.086 €/m^3; average cost of 1.76 €/m^3), and eventually exceeds it.

The measures for the **agricultural sector** are associated with conveyance and field application efficiency gains and include: converting for open channels to closed pipes, converting from furrow irrigation to sprinklers and to drip, converting from sprinklers to drip irrigation, and applying precision agriculture in drip irrigation systems. Two intervention curves have been developed, one for the Karditsa Prefecture (original combined irrigation efficiency is 77.4%) and one for the Trikala Prefecture (77.6%). The transactions from one method to another have been the object of the optimisation in order to define optmimal mixes of measures. It is observed that for Karditsa increasing efficiency by 5%, 10%, 20% and 29% (which is the max potential increase) requires an AEC of 0.47, 1.06, 5.97 and 7.39 mio € respectively. For Trikala the costs are higher (1.39 and 3.78 mio € for 5% and 10% respectively) but the actual efficiencies obtained are higher as well (since Trikala starts with a higher efficiency rates in the BaU). The max potential for Trikala is 17% with an AEC of 7.06 mio €). A clear correlation is observed between the combined irrigation efficiency and the irrigation method used (sprinklers vs. drip irrigation): efficiency gains are clearly observed in as the area irrigated with sprinklers decreases and is replaced by drip irrigation systems, while the application of precision agriculture (in the areas irrigated with drip systems) further boosts efficiency. To simulate the agricultural intervention curve into the WEAP WRMM of the Ali-Efenti, the WEAP's key variable "Irrigation Efficiency Coefficient" was used. The demand nodes (23 in total) have been divided to two large sections, falling under the prefectures of either Karditsa or Trikala, obtaining a respective value for the "Irrigation Efficiency Coefficient" variable. Efficiency gains of 5%, 10%, 15% and have been simulated by introducing the relevant efficiency coefficient values obtained from the intervention curves. It is observed that approximately 20%, 30%, and 50% reduction in the irrigation unmet demand can be achieved with an AEC of 4, 7.6, and 10.8 million € respectively (or 82, 162, 224 €/ha respectively). A maximum of 68% reduction can be achieved with an AEC of 14.5 million € (or 300 €/ha). Overall, we can observe that water savings accumulate incrementally as irrigation efficiency increases as a result of the applied measures. The largest incremental water saving in irrigation is achieved in the beginning, when irrigation efficiency increases by 5%, and amounts to a total of 23.3 mio m^3 for the entire basin (across all nodes). Above the level of 15% the incremental additional water savings are less pronounced, while no additional savings are observed if increasing the irrigation efficiency beyond 20% in the majority of the nodes. The largest savings are observed in the catchments of M.Rema2, M. Rema1, Pamissos-Mesdani, K. Lithaios and Portaikos.

- **Conclusion on the selection of optimal measures:**

To define the optimum mix of measures, across the urban and agricultural sector, and optimization process has been implemented. The main tools used for the optimization are the Ali-Efenti WRMM (developed in WEAP21) that simulates the hydrosystem, and Matlab that optimizes it. A bespoke code, handing the interaction between the two programs was developed in Matlab, using the COM-API available in WEAP21, and the Matlab toolbox and the NSGII algorithm were used for the optimization. Two optimization scenarios were developed, the first one using three decision variable (Wmu, Irrigation Efficiency Coefficient_Karditsa, Irrigation Efficiency Coefficient_Trikala), and the second one using a forth additional decision variable, the Deficit Irrigation. Deficit irrigation has a cost that is associated with the farmers' income loss, and was thus considered in a spate scenarios for cross-comparison. It has been simulated into WEAP by adding a user defined variables, and by inserting relevant data on crop yields and market prices. The objective function of the scenarios was to minimize agricultural unmet demand while minimizing the associated cost (investment and loss of farmers; income).

For **Scenario A** the maximum achievable unmet demand is about 22 mio m^3 (i.e. 80% reduction) with an AEC of about 18 mio €. The AEC in € for each m^3 saved are in the range of 0.10-0.20 for up to 80% reduction in unmet demand (i.e. about 90 mio m^3 of water saved). Investments above 18 mio € AEC could be disregarded as they don't introduce any additional significant savings. A 50% reduction in the unmet demand requires and AEC of 7.7 mio € (equivalent to 0.14 €/m^3 saved), and entails measures that will lead to a 12% increase in urban water savings, an 18% increase in Karditsa irrigation efficiency and a 10% increase in Trikala irrigation efficiency. The agricultural interventions are overall preferred by the algorithm. The implementation of urban water saving measures does not contribute significantly to the reduction of unmet demand. The algorithm prefers solutions which are associated with irrigation efficiency gains in the Karditsa prefecture.

For **Scenario B** an investment of about 8.5 mio € AEC (equivalent to 0.08€/m^3 saved) can eliminate unmet demand and result in full coverage of the water needs. This of course entails the application of 20% deficit irrigation. After that point further investments result in water surplus, up to 82 mio m^3 with an investment AEC of approximately 24 mio € and a 30% deficit irrigation. A 50% reduction in the unmet demand requires an AEC of 4.6 mio € (equivalent to 0.08€/m^3 saved) and entails measures that will lead to a 13.5% increase in urban water savings, a 12% increase in Karditsa irrigation efficiency and a 3% increase in Trikala irrigation efficiency, and the application of 5.2% deficit irrigation. A comparison across the two optimization scenarios shows that at the beginning, for water savings up to 40 mio m^3 (i.e. about 30% reduction of the unmet demand) both scenarios have similar cost-effectiveness (AEC up to 4 mio € or 0.1 AEC €/m^3 saved), since scenario B applies small percentages of deficit irrigation up to 3%. After that point, the cost-effectiveness of the two scenarios strongly deviates, with scenario B delivering higher water savings at a lower cost.

Summing up:

- Optimization of interventions in the urban environment indicates a maximum water saving potential equal to 62.7% with an investment cost of 79 mio € AEC. However, above the water saving level of 37%, the applied measures result in a cost higher than the average water price in the areas (1.4 €/m3), and include rainwater harvesting, greywater reuse and efficient washing machines.
- Both agriculture intervention curves indicate that in order to improve the combined efficiency of irrigation networks a high percentage of drip irrigation and precision agriculture is required.
- Optimization scenario A indicates a maximum of 80% reduction of unmet demand with an investment cost (AEC) equal to 18 mio €. An investment above that level has insignificant impact to the reduction of unmet demand.
- Optimization scenario B indicates that the use of deficit irrigation reduces dramatically unmet demand – albeit with a cost to production and hence income. An investment of about 8.5 mio € AEC (equivalent to 0.08 €/m3 saved) can eliminate unmet demand and result in full coverage of the water needs (100% reduction of unmet demand). This result, although intuitive, suffers from the problem that in practice farmers who have access to groundwater would use it, instead of conforming to deficit irrigation practices, hence tapping into non-renewable groundwater reserves.
- For a reduction in unmet demand up to 30% both scenarios have similar cost-effectiveness because the algorithms chose to apply small percentages of deficit irrigation in scenario B. After that point, the cost-effectiveness of the two scenarios strongly deviates, with scenario B delivering higher water savings at a lower cost.
- The agricultural interventions are overall preferred by the algorithm in both scenarios, as compared to the urban interventions. The penetration of urban water saving measures does not contribute as much to the reduction of unmet demand, and thus the most cost-effective solutions implement a maximum of about 12% saving in the urban sector.

- **Conclusions on the simulation of future scenarios:**

The **future climate (CC)** has been analyzed under the A1B scenario with temperature and precipitation obtained from the RACMO2 model output for the period 1960-2030 from 16 locations (output nodes). It is observed that in some locations the mean daily precipitation will decrease, while in others will increase: around 3% decrease in the northern part of the Ali-Efenti, and 1-2% increase the southern part. A higher increase in the number of dry days is expected in the southern and the northwestern part (up to 5% and 6%

respectively), and a less prominent increase is expected in the northeastern part. The mean annual precipitation will increase in 12 sub-catchments, decrease in 5, and remain about the same in 6 sub-catchments. On a seasonal basis, precipitation is projected to decrease during winter and summer, and increase during spring and autumn. The potential crop evapotranspiration is projected to rise about 2.3%, mostly during the irrigation season.

The **future socio-economic conditions (SE)** have been analyzed building on the SCENES "Economy First" scenario, while incorporating some elements of the SCENES "Policy Rules" scenario, and have downscaled and "translated" for Greece. The resulting scenario is named G1 "Confident & Competitive Greece", and foresees the adoption of an open and liberal economy, with a main target to increase competitiveness and to develop comparative advantages. The underlying assumptions of the scenario are the globalization trend, the liberalization of the markets, the balanced exploitation of fossil fuels and renewable energy, the enhancement of decision-making at the international level and the decisive influence of markets/business in policy-making. The quantification of the results with the International Future (IFs) software resulted in: 1-1.5% population increase, 2-4% reduction in grassland, 0.3-0.7% increase in both forests and agricultural areas, 15-25% in water use, 26-43% increase in agricultural production, 15-25% increase in meat production, and 36% increase in hydropower production. The G1 also assumes changes in crops, due to the driver to cultivate more profitable crops, and thus 15-20% of cotton and maize will be replaces by kiwi, broccoli, and aloe vera.

The simulation of these scenarios in the WRMM (by fine-tuning the relevant model parameters) shows that under the CC scenario total demand is expected to increase by 2%, due to an increase in irrigation water demand. Although water demand will increase, the unmet demand will decrease by roughly 3% since the potential water supply is now higher as a result of the higher precipitation. Under the CC-SE scenario the total demand is expected to decrease by 4%, due to the decrease in irrigation water demand (by ~5%) as a result of the irrigated crop changes. The domestic, industrial and livestock water demands will increase by 6%, 14% and 19% respectively, due to an incremental increase in daily water use rates and population, industrial production and animals' population. The unmet demand will be significantly reduced by 46.5%, mostly attributed to the expected 46% decrease in the unmet irrigation demand. Consequently, the overall water demand coverage is expected to increase under both scenarios, from 93.52% in the 1995-2010 Baseline, to 93.80% in the CC, and 96.38% in the CC-SE.

- **Conclusions on the robustness of the measures and the target setting:**

The selected optimization solutions seem to be suitable for reducing unmet demand under both CC and CC-SE scenarios, and under average and extreme (driest year) conditions. For average conditions, the vast majority of the solutions result in a total elimination of unmet demand and start delivering water surpluses. For the driest year (i.e. representing the most conservative case), this is achieved by half of the solutions, and the associated total costs range from AEC 7 to 13 mio €. The solutions of scenario B result in greater savings due to the application of deficit irrigation.

The solutions also differ among them in terms of the breakdown of costs per sector (urban vs. agriculture), the breakdown of costs within the agricultural sector (i.e. investment cost for improving efficiency vs. loss of farmers' income associated with deficit irrigation), and the unit cost for each m3 saved (€/m3). Thus, they fit different purposes, each one with each one advantages and disadvantages. Which solution(s) will be finally selected in order to define relevant targets is subject to the policy goals to be achieved. This decision-making process needs to implement a multi-stakeholder participatory approach, so that the goals to be achieved are defined within a rational and publicly accepted reasoning, and the subsequently defined targets can serve these goals.

8.9.2 Key messages

A number of key messages can be derived from the Ali-Efenti case study regarding the validation of the methodological approach:

- The **WEAP21 environment** was found to be user friendly, while allowing a lot of flexibility to the modeler providing various options and methods to simulate the different features, depending on the degree of data availability. Its built-in functions are useful for developing intermediate modeling steps, while the supported scripting possibilities provide good opportunities for customization. The user can easily develop analytical expressions to calculate key outputs, by defining key assumptions, and thus can easily examine alternative scenarios when changing these key assumptions. The model also offers the opportunity to develop different scenarios (accounts) and compare across them. From all the above, it is concluded that WEAP21 is a valuable tool is such applications, even in cases where data are limited and need to be estimated through proxies.
- The **testing of the DHI** in the area has revealed that this index is suitable for characterizing meteorological drought, capturing all its characteristics (recurrence, severity, magnitude, duration), and hydrological drought (as validated against

streamflow data). It is easily reproducible indicator, based on readily available precipitation data, transparent. Its sensitivity allows for comparisons between different areas. It can be calculated for different time periods, permitting thus the assessment of the evolution of drought hazard over time and the detection of trends, while its historic context is suitable for decision making. Finally, the DHI allows for easy integration with additional relevant indicators of environmental or socio-economic context, necessary for the analysis of relevant vulnerabilities and risk.

- The **testing of the DVI** in the study area demonstrated that this index is pertinent to main objectives of vulnerability assessment in water-stressed areas, and is able to integrate physical exposure and social-economical determinants. It is easy to understand and interpret, transparent, flexible and sensitive, as it allows for the identification of hotspots and changing trends.
- The **DRI is found to be** an adequate tool, in developing Drought Risk Profiles, policy-relevance is areas under water stress, and useful in guiding decision-making. It can be obtained at different spatial and temporal scales depending on the level of the desired analysis, and underpin the definition of policy targets.
- The **developed DSS** (for the purpose of the global optimization) is model-driven, and it has been proven adequate to support the decision process with regard to the selection of optimal interventions. The design concept is based on the Parametrization-Simulation-Optimization (PSO) framework (Koutsogiannis and Economou, 2003). A main advantage is the fact the process is parsimonious, and this is attributed to pre-defining intervention curves. Instead of having numerous decision variables (one for each measure), these were narrowed down to only four. Since optimization has already been applied within the intervention curves, optimal mixes of measures had already been defined and thus the decision space of the DSS was reduced, reducing complexity and making convergence faster. The access and manipulation of the DSS is relatively simple, while the operational requirements are medium-low. Also, the system is stable, adaptable and expandable should the user require to add or remove decision variables and/or objective functions. It is considered adequate to underpin decision-making with regard to the selection of optimum mix of measures, and answer policy questions of current or future interest.
- The **climate and socio-economic scenarios** developed for the Ali-Efenti build on, and are downscaled from widely accepted EU scenarios. Nevertheless, uncertainty is incorporated in these scenarios, thus careful interpretation is needed. With regard to the climate change scenarios, it is more relevant to consider the relative changes in the

meteorological parameters between the future and the baseline, as opposed to absolute values. Since under or over-estimation are common, bias correction against observed data is suggested. With regard to future socio-economic changes, the GEO4 sensations (and surrogates such as the SCENES) can provide a basis, but it is necessary to formulate a concrete storyline for the area on interest with input from the stakeholders, so that the scenario is more plausible. It is also important that the selected CC and SE are aligned in terms of the global driving forces and based on similar storylines (i.e. not on contradicting basic assumptions). The WEAP21 as a modeling environment provides flexibility and good options in simulating different scenarios by fine-tuning key parameters and expressions.

- The **robustness analysis** is very useful in drawing conclusions on the optimization-based selected solutions, since some of them may be found to over-perform or under-perform under the future climate and socio-economic conditions. The analysis can further assist in the decision-making process and the definition of targets, since it provides insight at specific sub-components such as the share of costs across the sectors, or across the main actors (i.e. government vs. farmers). Target setting must be based of the definition of clear policy goals, which are based on a solid and transparent rationale, so that are realistic, feasible and publicly accepted.

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CHAPTER 9 – CONCLUSIONS AND DISCUSSION

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9 CONCLUSIONS AND DISCUSSION

9.1 Pertinence of the research objectives to current environmental and societal challenges

The overall objective of the current research is to develop operational methods and tools for supporting Drought Risk Management (DRM) in water stressed areas. The proposed methodology is holistic, based on the recently developed concept of mainstreaming (UNDP, 2011) and develops a set of relevant tools for proactive drought risk management and planning, implementing a step-wise approach that integrates physical and anthropogenic drivers and pressures, impacts and response. The elaborated methods and tools cover all components which need to be accounted for in drought risk management, spanning from the drought hazard evaluation, to the assessment of water resources availability and demands across economic sectors, to mapping of water scarcity vulnerability and developing drought risk profiles, and finally leading to the design of optimal mitigation measures, linking them to the decision-making process in order to set policy targets for internalizing them into development programming frameworks.

The grounds of the current research are concurrent with widely recognized problems and challenges related to the drought hazard, and the tools developed hereby are pertinent to supporting key, state-of-art aspects of proactive drought risk management. The physical problem to tackle, i.e. drought, is becoming more and more frequent and severe worldwide, while there is an increasing risk of drought and water scarcity as recognized at the higher political level by various agencies and international stakeholders. The social, political, environmental and economic costs of drought are evident across the globe. In Europe, at least 11% of the European population and 17% of its territory have been affected by water scarcity to date. Recent trends show a significant extension of water scarcity across Europe (EC, 2007a). The year 2003 was the one with the highest number of countries affected in Europe (18 countries in total). More than 100 million people and one third of the EU territory were affected, while the cost of the 2003 drought to the European economy was at least € 8.7 billion.

It is clear that response and adaptation measures are needed to mitigate drought (and water scarcity) impacts, but these may differ substantially, depending on the issues and priorities of each region. The fundamental drought risk, the state of implementation of response measures, the selected management approach, as well as the prevailing policy and institutional frameworks differ among the different countries and regions. Furthermore, the effectiveness of the response measures is difficult to be evaluated as it is related to many socio-economic factors. Traditionally, most attempts to manage drought and water scarcity, and their related impacts, focused on a rather reactive crisis-management approach resulting thus in being ineffective, untimely and unsustainable on the long term. There are many factors which have led to poor drought management, and these relate both to the nature of drought hazards, as well as to the management approach traditionally adopted, such as: the lack of a universally accepted definition which confuses the characterization of drought (degree and severity), the creeping character of drought which obscures its identification, the wide range of indirect impacts which are difficult to monitor and quantify, the lack of concrete methodologies on drought risk management and planning, the lack of robust drought policy frameworks and public awareness. Nevertheless, the need to move towards proactive drought risk management is clearly identified, at national and higher political levels, and this entails identifying where vulnerabilities exist (particular sectors, regions, communities or population groups) and addressing the related risks through systematically implementing mitigation and adaptation measures that will alleviate the risk associated with future drought events. There are numerous and diverse drought mitigation measures, but are often less obvious to the affected population and stakeholders since often non-structural. These include, but are not limited to: development of early warning systems, seasonal drought monitoring and forecasting, demand management and water saving, planning for additional and/or alternative water supply. Among them, demand management measures have gained recognition as to their sustainability and reduced environmental impact, as also suggested in recent EU Communications (EC, 2007a; EC, 2012a).

9.2 Credibility and added-value of the overall methodological approach

The methodological approach builds on the UNDP concept of "Mainstreaming Drought Risk Management". This concept was developed based on an extensive review of existing documentation and practices in drought risk management (DRM), climate risk management (CRM) and adaptation to climate change at different levels (UNDP, 2011), and outlines a stepwise approach in defining, and subsequently translating, drought risk assessments into specific policy measures, planning instruments and measurable interventions.

Five basic steps are involved in the UNDP DRM mainstreaming process (UNDP, 2011), starting out with (Step 1) a broad-based stakeholders' identification and engagement, and the set-up of a multi-sectoral stakeholders' coordination mechanism to ensure the successful implementation of all the following mainstreaming steps. The second step (Step2) involves establishing the scientific basis for DRM, and entails the assessment of the hazard and vulnerability (as shaped by the prevailing by socio-economic, policy, cultural and environmental conditions), and the development of the resulting drought risk profile.

The third step (Step 3) deals with the identification and prioritization of various DRM options at different levels and scales (short-term preparedness measures to longer-term mitigation options). The forth step (Step 4) is to internalize the DRM measures in the development policy and planning frameworks (entry points). The fifth step (Step 5) entails the monitoring and measuring of the impacts of DRM mainstreaming process. Reviewing the concept of mainstreaming, in the framework of the current research, it is concluded that it is sound and further incorporates added-value elements:

- It fits well with the context and essence of proactive drought risk management, while it places an additional emphasis on implementability and sustainability issues, by opting at the internalization of the DRM measures in the development policy and planning frameworks.
- It helps to redefine drought, not just as a natural phenomenon, but as a more complex development and sustainability issue (substantive mainstreaming)
- It supports multiple goals: penetration of measures in local development programmes, development of cross-sectoral and mutually reinforcing policies, leveraging of national and international resources throughout the planning, funding and implementation stages of any development framework

- It ensures that sectoral policies do not counter their intended purposes of drought mitigation efforts
- Is helps the creation of an enabling environment to reinforce the adaptive capacity of communities and societies in a sustainable fashion
- It supports the identification of mainstreaming entry points
- It supports the integration of DRM at sub-national and local levels (although the process is mainly described from a central government perspective), and the development of decentralized DRM roles and responsibilities, through the potential for integration into the local development plans.
- It provides a useful roadmap for designing and implementing an effective DRM strategy, while maintaining a flexible and adaptable character.

The conceptual DRM framework implemented in the current research is well-harmonized with the UNDP mainstreaming framework, which adds to its credibility. The core steps remain the same (i.e. definition of a drought risk profile, identification and prioritization of options), but some of the UNDP steps are considered here as ancillary elements and supporting tools rather than concrete individual steps. For example, setting-up a stakeholders' coordination mechanism (step 1 of UNDP) is considered as an activity/tool supporting the definition of Drought Risk Profiles and DRM Internalization rather than a stand-alone step. Similarly, measuring the impact of DRM mainstreaming (step 5 of UNDP) is also seen as an element of the successful implementation of step 4 (Internalizing DRM). To achieve the implementation of the DRM mainstreaming concept, the current research proposes a set of operational methods and tools (for each step of the process), which are nicely interlinked. They can be utilized as stand-alone tools, or components of an integrated support system. These developed methods aim to provide an interface between science and policy, and deliver to decision-makers tools that help them materialize the different mainstreaming steps based on engineering best practices and informed knowledge. The following quality elements are identified with regard to the overall methodological approach developed in the current research:

- It is **generic**, stepwise, **flexible** and easily **adaptable**: it can be modified and adapted to various area-specific contexts, sectoral structures, and technical arrangements, serving as a useful guide for various drought risk management projects.

- It is **modular** and **expandable**: it comprises of engineering components (tools) which can be implemented as stand-alone or as components of an integral system, depending on the needs of the user, the maturity of the project under investigation, etc. Additional components can be added ad-hoc should the user requires to do so (e.g. additional mitigation measures such as wastewater reuse in agriculture, additional intervention curves, etc.).
- It is **parsimonious in terms of data needs**: the necessary input data to the various tools are relatively easy to acquire (e.g. precipitation, water demand, costs, yields, etc.).
- It is **trans-disciplinary**, and integrates environmental (biophysical) with social-economic issues at various spatial scales, within a range of time perspectives, and supports the assessment of relevant drought risk profiles.
- It **supports the design** of medium to longer-term mitigation options, helping thus to remove structural barriers.
- It can support a **drought risk sensitive development approach** at national, sub-national and local levels, and across sectors, by delivering an optimization-based selection of the most cost-effective intervention options.
- It enables the definition of **sectoral policy targets** (on the basis of a robustness check against future climate and socio-economic scenarios), supporting thus the mainstreaming of DRM options into the planning, funding and implementation stages of any development framework.

9.3 Development of Drought Risk Profiles

The methodology proposed for developing Drought Risk Profiles is based on overlaying the drought hazard and vulnerability components, following the basic definition of risk being a product of hazard and vulnerability (risk = hazard x vulnerability). The drought hazard and vulnerability are assessed through the developed Drought Hazard Index (DHI) and Drought Vulnerability Index (DVI) respectively.

A plethora of indictors and indexes of different complexity are available for drought hazard analysis, mainly attributed to the many definitions of drought. The last advances attempt to combine and aggregate multiple indicators, into generating specialized drought indices, tailored to the context of the problem in-hand and making use of all available information (e.g. US Drought Monitoring, NDMC, 2008). Debate is yet still ongoing as to the fact that aggregated indices may hinder the proper representation of the problem since too aggregated. As a result, the selection of an appropriate index which minimizes on one side the hydrological information required, while it is robust enough to accurately characterize the drought hazard is still challenging. Similarly, numerous indicators providing some representation of water scarcity and stress, bearing different names and definitions, are developed globally. Yet, no single common approach is adopted when it comes to characterising water stress conditions. Some of the indicators only provide some awareness-level relevant information since highly aggregated in terms of temporal and spatial resolution, while others attempt to identify hotspot areas adopting a smaller spatial scale of analysis. It is nevertheless apparent that no systematic assessment is available.

The current research defines a methodology for investigating the spatial and temporal variability of drought hazard based on a new index, the DHI, accounting for the intensity, magnitude, duration and frequency of drought events, which is based on aggregation of four sub-indicators derived from a post-processing of the commonly used Standard Precipitation Index (SPI). These four sub-indicators reflect: the number of drought episodes (events) observed within the reference period (recurrence), the number of drought episodes with duration greater than 24 months (severity), the maximum drought magnitude observed (magnitude), and the maximum duration (in months) among the drought episodes observed within the reference period (duration). The results of the validation of the DHI in the Ali-

Efenti River Basin (Kossida and Mimikou, 2015) and Upper Tiber Basin (Maccioni et al., 2015) demonstrated that is supports the assessment of the evolution of drought hazard over time and the detection of trends, while its historic context is suitable for decision making. Specific conclusions on the performance of DHI are drawn below, while its scoring against commonly used assessment criteria for indicators is provided Table 9.1. On the basis of its performance we can conclude that DHI has an operational value and could be used to serve policy needs. More specifically it is deemed:

- **Suitable for characterizing** meteorological drought, capturing all its characteristics (recurrence, severity, magnitude, duration), and hydrological drought (as validated against streamflow data)
- **Flexible** enough to be computed for multiple timescales relevant to the drought analysis
- **Easily Reproducible** indicator, based on readily obtained precipitation data which are commonly of high quality
- **Robust** since useful over a wide range of physical conditions, and responsive but not temperamental, with a demonstrated temporal and spatial sensitivity
- **Relatively Tractable**, since it has a practical computability, medium-level numerical computing, and relatively simple steps of the computation
- **Transparent**, since it has clear objectives and rationale, and is understandable not only by scientific community but by the policy and decision-makers as well
- **Sophisticated**, with a conceptual soundness, based on the well-acknowledged SPI (Quiring, 2009).
- **Extendable**, since it can be easily extended across time to alternate sequences and histories as it relies upon basic measured precipitation data
- **Dimensionless**, and thus useful for comparing features between different locations and/or periods. At the same time its 4 sub-indicators have fundamental units and/or ratios computed from physical units which is also considered advantageous
- **Easy to integrate** with additional relevant indicators of environmental or socio-economic context, which are necessary for the analysis of relevant vulnerabilities and risk (e.g. population density, land use, water exploitation, unmet demand, etc.).

Table 9.1: Scoring of the DHI against common performance criteria

Criterion[1]	Weight[1]	Relative Importance[1]	Awarded Score for the DHI *(max=5, min=1)*
Robustness	8	28%	5
Tractability	6	24%	2
Transparency	5	17%	4
Sophistication	5	17%	4
Extendibility	3	10%	5
Dimensionality	2	7%	4
Weighted Total Score			115

[1] Keyntash and Dracup, 2002

With regard to characterizing and assessing Drought Vulnerability, numerous conceptual frameworks, methods and models have been identified and explored. They can be generally grouped under two perspectives, associated also with the evolution of the concept of vulnerability: (a) the technical or engineering sciences perspective, and (b) the social sciences perspective. The former focuses mostly on the physical aspects of the system and on the assessment of hazards and their impacts, while the latter focuses on the human system and on determining the capacity of the society to cope, respond and recover from the impact of a natural hazard. The various models used for assessing vulnerability incorporate, in general, parameters with reflect the physical, economic, social, environmental, political and institutional dimensions. Although these assessments have several common aspects, regardless of the framework or school they are based on, they also have limitations which impede their comparability and reproducibility under different areas since they tend to be specific or context-dependent. Concluding, it is identified that the various methods and approaches for assessing drought vulnerability (and the resulting risk) are exemplifying the complexity around the issue. This complexity is attributed to the fact that drought vulnerability is multi-dimensional and differential, scale dependent and dynamic. No universal frameworks exist, while consensus around the criteria, parameters and thresholds used has not been reached.

In the current research a specific index, the DVI has been developed to assess vulnerability. The use of this single index, as opposed to a blend of indicators reflecting different socio-economic aspects, is based on the rationale that the most important goal when developing tools or methods for assessing and quantifying drought vulnerability is their use in supporting risk reduction strategies, and their operational application in the decision-making processes. In this context unmet demand is identified here as the main pressing factor and impact to mitigate. Unmet demand adequately reflects the pressure caused on the society by the irregularity of the natural process, and incorporates different vulnerability components which are commonly discussed in literature, such as population, land use, irrigated areas, etc., since these are in fact the main drivers of the water demand. It also incorporates, indirectly, the current practices in the area of analysis, since it is on the basis of these practices that unmet demand occurs. Should a change in practices (e.g. adoption of water saving measures) be implemented, this would normally be reflected as a decrease in unmet demand (rebound effects may of course be applicable here which can hinder the problem). On the basis of unmet demand, three sub-indicators are proposed to be blended into a vulnerability index, which reflect metrics of reliability (% of years with unmet demand), distance to target to meet demand (average unmet demand) and resilience to extreme conditions (maximum annual unmet demand). The DVI indicator has been validated in the Ali-Efenti basin. The main conclusions with regard to its added-value are summarized below:

- It is **pertinent to main objectives** of vulnerability assessment in water-stressed areas, where the imbalance between availability and demand is often a structural condition.
- It **integrates** physical exposure and social-economical determinants as unmet demand is the result of the imbalance between natural availability and anthropogenic water demand
- It is **readily understood**, **easy to interpret** and use, as opposed to a blend of indicators, which requires further analysis and interpretation as to what is the key message from the combined effect of all determinants.
- It can be calculated at **different spatial and temporal scales** depending on the level of the desired analysis, and can reflect the spatiotemporal variability of vulnerability since calculated on a distributed basis.
- It is **sensitive**, spatially and temporally, allowing for the identification of hotspots and temporal trends.
- It is **policy-relevant**, since it can be directly linked to drought management goals and used as a direct input in supporting risk reduction strategies and decision-making.
- It **internally captures** the main drivers and pressures of water demand (and hence vulnerability) such as population, land use, irrigated areas, current practices, etc.

- It provides a **pure quantitative** vulnerability assessment outcome (as opposed to semi-quantitative or qualitative), providing thus a more explicit objective framework which may be conducive to improving the decision-making process. Of course, it is not totally devoid of expert judgment since this is used in the definition of classes and thresholds
- It provides **more objective metrics** than other vulnerability indices which are based on blended indicators assigning specific weights, often subject to subjectivity.
- It is **relatively easy to define scales and thresholds**, as opposed to multiple-indicator vulnerability frameworks where the indicator scales and thresholds values need to be statistically consistent, validly compared, and combined in decision-making (which is often very problematic).
- It allows for an **easy visualization and comparison**, through the derivation of relative maps
- It can be **broken down into sectors** (i.e. unmet demand per sector) further supporting sectoral policy relevant assessments, and development plans
- It can **be easily integrated** with additional relevant indicators, such as hazard indicators, resulting in the assessment of risk
- It may be **relatively difficult to compute unmet demand** if direct data on water supply and demand (or use) are not available. In this case it requires the development of a detailed distributed water resources management model, and adequate resources to support this infrastructure
- It can increase **transparency and soundness**, and hence the acceptance of the scientific findings, as it reflect the result of **uncertainty and sensitivity analysis** (i.e. unmet demand can be computed under different scenarios, or alternative future by using empirical, probabilistic or other modeling approaches).

To profile drought risk, the Drought Risk Index (DRI) is considered an adequate tool. The DRI is based on the combination of the Drought Hazard Index (DHI) and the Drought Vulnerability Index (DVI), and maintain the prevailing characteristics of the DHI and DVI. Consequently it can be obtained at different spatial and temporal scales depending on the level of the desired analysis, and carries-on the quality elements and added-value of its components as highlighted above. On the basis of DRI, the drought risk profiling can be easily visualized through maps derived for the area of interest (River Basin District, River basin, sub-catchments), policy-making, and directly contribution to decision-making and policy implementation.

To further strengthen the evaluation and application of the developed indices, the following components have been identified as suitable for future research:

- In the current research it is suggested to calculate the DHI at each rain gauge station in the area under investigation, and then interpolated them across the entire study area to obtain a full coverage. Alternatively, an interpolation of the precipitation can be first implemented, followed then by the calculation of the DHI. This approach was not adopted here, since it will entail very large computational time. It also needs to be handled by a specific programming script, developed e.g. in Matlab and linked to GIS. It basically means that the areal precipitation should be derived for each month (based on interpolation), and then a Gamma distribution must be fitted to every grid cell to transform the precipitation timeseries into SPI timeseries. The DHI needs then to be calculated for each grid cell. It could be interesting to implement this procedure and compare the obtained results with the ones obtained through the original approach, reflecting thus on the consistency of the two methods.
- To further conclude on the suitability of the DHI in capturing different types of drought in different areas, one could investigate deriving the DHI using different SPI scales (e.g. SPI-3, SPI-6, SPI-24) and link them to observed impacts in soil moisture, streamflows and groundwater.
- A benchmarking exercise, i.e. calculating and comparing DHI across different areas could assist in the fine-tuning of the proposed thresholds and classes. It is of course recognized that drought hazard has a regional character, and universal thresholds may not be applicable, but research could benefit from an insight on this aspect.
- The basis of calculation of the DHI, which is the Standard Precipitation Index (SPI), could be replaced by a similar indicator which also considers Evaportanspiration additionally to the Precipitation (P-ET). For example, instead of the SPI the following indicators could be used as a basis for calculating the DHI: the Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007), the Standardized Precipitation Evapotranspiration Index (SPEI) (Begueria et al., 2010; Vincente-Serrano et. al, 2010a, 2010b), and the recently suggested Standardized effective Precipitation EvapoTranspiration (SP*ETI) (Maccioni et al., 2015).

- To further conclude on the suitability of the DVI in capturing vulnerability to drought in different areas, one could investigate its link to observed impacts (e.g. economic, loss of production, decrease in yields, environmental impacts, etc.) in areas that have experienced drought and water stress.
- A benchmarking exercise, i.e. calculating and comparing DVI across different areas could assist in the fine-tuning of the proposed thresholds and classes. It is of course recognized that drought vulnerability has a regional character, and universal thresholds may not be applicable, but research could benefit from an insight on this aspect.

9.4 Design and optimization-based selection of demand management measures

The recent assessment of the Water Framework Directive River Basin Management Plans (WFD RBMPs) showed that water supply measures are significantly stronger reflected in the screened set of plans (about 30-40% of RBMPs) than restrictions of pressures (e.g. new water-demanding urban or agricultural developments), demand management measures or measures to ensure the achievement of the environmental WFD objectives under water scarcity and drought conditions (EC, 2012). Evidence on the impacts of applied response measures is limited and no concrete conclusions can be drawn on their effectiveness (Schmidt and Benitez, 2012). It is thus important to simulate response measures (and a bundle of them) against the physical systems, in order to test their applicability and assess their true potential under specific conditions and constraints, prior to defining drought risk mitigation and policy actions.

The methodology proposed here for addressing the above challenges consists of three components: designing, simulating, and optimizing, and builds on the Parameterization-Simulation-Optimization (PSO) framework (Koutsogiannis and Economou, 2003). These components are interlinked into a DSS, comprised of:

(a) The intervention curves which simulate the cost-effectiveness of optimum bundles of urban and agricultural measures, and which can be considered as a "Library";

(b) The WEAP21 model, which is the "Simulation Engine", used to evaluate the impact and effectiveness of the measures on the physical-based reality under different scenarios, and estimate the yields and market values of the crops, and

(c) The MATLAB-GA, which serves as the "Optimization Engine", used for the selection of the mix of measures across the urban and agricultural sectors in order to minimize unmet demand with the minimum AEC.

The main advantages of the proposed DSS and its sub-components are presented below:

- The methodology for **designing demand management measures**, incorporating the development of cost-effective intervention curves, **is generic** and able to be adjusted under different regional context and expert input from stakeholders.

- The **intervention curves are easily adaptable**: they can be adapted and updated at any time, just by changing the primary input data (e.g. costs).
- The **intervention curves are expandable** and **reproducible**: adding or removing technologies to/from the intervention curves is easily handled, in order to tailor them to specific areas and contexts. They can be enriched with additional measures, or they can be extended to include additional typologies of measures (e.g. increase supply measures).
- The **parametrisation** of the demand management measures (interventions) is **parsimonious**, via a small number of decision variables that need to be inserted into the physical WRMM.
- The methodology **incorporates the simulation of the researched measures** against the physical system, in order to assess their actual impacts and effectiveness on the physical-based reality.
- The proposed **"simulation engine" WEAP21 can adequately represent** complex physical and socio-economic systems, capturing all the salient features of the hydrological cycle and providing different options and functions to model water supply and demand.
- The proposed **"simulation engine" WEAP21** provides scripting flexibilities so that user defined variables can be inserted in the model allowing the simulation of various bundles of measures as red through the intervention curves.
- The proposed **"simulation engine" WEAP21 can support scenarios analysis**: a set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, and hydrology, can be explored.
- The proposed **"optimization engine" MATLAB** can be **linked to the WEAP21** through its COM-API, directly feeding the outputs of the optimization to the WRMM and vice versa.
- The **objective function(s)** that express the desired performance metric(s) are **simple** and **adjustable.** The design of the optimization problem as multi-objective can accommodate the various stakeholders' needs, which are often conflicting.
- The **global optimization process is parsimonious**: decision variables are obtaining their values from the developed intervention curves, which already resulted from an optimization process, and thus the decision space of the solutions is already reduced, and the optimization model's complexity is reduced and remains relatively simple.

- The **global optimization process is relatively cheap**: the optimization process leading to the definition of the optimal mix of measures is carried outside the WRMM, and selected solutions of the pareto front can be then simulated in the WRMM at a second step. This makes the global optimization **less time-consuming**.
- The definition of the **optimum mix of measures is underpinned by state-of-art algorithms**, and looks across sectors. It can thus provide informed knowledge to stakeholders, based on best-available-science, and facilitate the formulation of sectoral and national policies, development plans and conflict resolution.
- The proposed DSS has the capacity to link interventions to the decision-making process in a transparent and easily communicated manner. It can also support multiple independent or inter-dependent decisions, and individual, group or team-based decision-making. It is of course contained by the knowledge supplied to it, and has inherently limited reasoning processes.

To further strengthen the evaluation and application of the DSS and it sub-components, the following areas have been identified as suitable for future research:

- Systematize the development of intervention curves in the urban and agricultural sectors by developing an extended library of cost and benefits per measure, for a wide range of measures, which can also include water quality and pollution prevention measures, natural retention measures, increase supply measures, etc. Land use changes (as examined in the case-study under the SE scenario) can also be introduced in the intervention curves but caution needs to be taken in the definition of their upper boundaries/ degree of penetration so the reflect a plausible reality. Perform some benchmarking exercises across costs and benefits in order to develop "prescribed" intervention curves for different settings (i.e. grouping), on the basis of economical or environmental conditions.
- Expand the intervention curves to additional sectors. For example, intervention curves can be built for the industrial sector. These can include multiple curves depending on the type of industry, e.g. textiles industry, foods and beverages, etc. They can also include generalized curves in areas where water efficiency measures are applicable for a wide range of industries: e.g. water savings induced by increasing cooling towers and boilers efficiency (which are used in numerous industries).
- Explore the possibility to embed more sophisticated cost functions in the intervention curves. Such functions could consider (on top the investment and operation cost, and the

farmers' income loos) transactions costs, hidden costs, lost opportunity costs, etc. Also, the objective function of the optimization of the intervention curves could look at additional economic indicators such as IRR (internal rate of return), ROI (return of investment), etc.

- Explore possible improvements in the optimization process by reducing the total computational time required. While the choice of MOEAs is justified by the generic nature and global search capabilities of these algorithms (Coello Coello et al., 2007; Zhou et al., 2011), a significant number of iterations is generally required to accomplish an adequate approximation of the Pareto front (Brockhoff and Zitzler, 2009). Especially when dealing with complex models (such as many highly distributed WRMMs) this might be a drawback. To this extent it may worth investigating the potential of Efficient Global Optimization (EGO) algorithm (Surrogate Based Optimization – SBO method), which is capable of reaching global optima within a few simulation model evaluations (~500 or less). Tsoukalas and Makropoulos (2015), suggest that EGO has the potential and the capabilities to handle computationally demanding problems, and furthermore is capable of locating the optimal solution within few simulation model evaluations after testing EGO in the coupled WEAP-MATLAB hydrosystem of Nestos.

9.5 Definition of policy targets – Internalizing DRM

In order for DRM options to attain sustainable results they must be translated into concrete sectoral and policy targets, based on a robustness analysis, and then integrated in development frameworks and implemented by the relevant bodies. This process includes three phases: (a) the definition of policy targets (designing phase), (b) their internalization into national, sectoral, or local development agendas and plans (integration phase), and (c) implementation by the relevant governmental bodies (implementation phase).The following main remarks are relevant to this process:

- To conduct a robustness analysis, the optimization-selected options must be evaluated for their behavior against alternative future conditions. These conditions are commonly simulated through scenarios, which build on narratives and storylines. Global climate change and socio-economic change scenarios are available (such as the IPCC SRES, the GEO-4 and the EU SCENES) and can be used as a basis for downscaling in the areas of interest. Yet, caution needs to be taken since uncertainty is incorporated in these scenarios, while they may not able to capture local specificities, and is thus suggested to use the as a basis rather than a sine qua non.
- Scenario development is traditionally characterized by identifying key drivers and critical uncertainties surrounding their future evolution, making assumptions about how these critical uncertainties will evolve, and exploring the broader implications of these developments. Behind these different drivers are the decisions by key actors, such as whether to act reactively or proactively with respect to environmental change. In addition, assumptions are made about key system relationships, such as the precise sensitivity of the climate system to increased concentrations of greenhouse gases (GHGs), or the exact effect of a reduction of crop yields on the health of some groups. From this perspective, the evolution of many of the drivers, as well as the pressures, state and impacts, are themselves part of the unfolding of the scenarios and not a priori assumptions.
- When defining policy targets a participatory approach, involving all stakeholders is paramount. Policy targets must be specific, measurable and time-bounded, and directly contribute to the achievement of the goal. The selection and prioritization of the target must be based on specific well-define criteria, such as: policy relevance, clarity,

robustness, attainability, scalability, quantification, measurability, multi-dimensionality, complementarity, ability of integration.

- To properly internalize targets into development plans (policy integration phase) it is necessary to define possible entry points, initiate instruments and mechanisms to internalize the targets, draft suggestions how to implement DRM in action plans, development programmes, etc., identify the necessary preconditions and enabling factors. The following elements must be considered: the time frame to achieve the target, the placement of the target at the appropriate level (national, subnational, regional), the definition of the nature of the target (binding, non-binding) and the enforcement method (voluntary, legal requirement, etc.).
- To properly evaluate the progress made towards achieving the defined targets, and thus the overall success of the DRM mainstreaming, appropriate indicators must be selected. These indicators must be quantifiable, while monitoring and evaluation should be conducted on a regular basis to allow for early identification of problems or malfunctions and the potential re-design of the policy targets. They key questions to be evaluated by the indicators relate to the relevance, efficiency, effectiveness and sustainability of the DRM mainstreaming, as observed by its impacts (overall, sector sceptic, etc.). The focus of the indicators must thus be on impacts, but since the later often require long time in order to be perceived, it is also advised to have parallel indicators on outcomes and outputs, which can convey a outlook of the progress made and distance-to-target at earlier stages of the implementation.

9.6 Chapter References

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ANNEX 1

Roadmap to the 2007 EC Communication on Water Scarcity and Drought (WS&D) and follow-up assessment of the 2012 WS&D Policy Review

Table A1.1: Roadmap of EU policy actions and initiatives related to WS&D.

Date	Action
November 2003	The informal meeting of the EU Water Directors agreed to develop an initiative on WS&D issues. A Drafting Group for Water Scarcity, led by France, Italy and Spain, within the WFD Common Implementation Strategy (CIS) was set up by the Water Directors to produce a Technical Document on drought events and water scarcity issues.
2004	The MED-EU Water Initiative/WFD Joint Process (MED JP WFD/EUWI) participated in the production of the Technical Document by the Drafting Group for Water Scarcity, and set-up a Mediterranean Water Scarcity & Drought Working Group (MED WS&D WG)
June 2006	The Drafting Group on WS&D and MED JP WFD/EUWI produced the Technical Document "Water Scarcity Management in the context of WFD" (MED JP WFD/EUWI, 2006b[Error! Bookmark not defined.]) and a Policy Summary (MED JP WFD/EUWI, 2006a[Error! Bookmark not defined.]) on WS&D, which was presented and endorsed by the Water Directors (02/06/2006). The Water Directors also agreed to set-up an Expert Network on Water Scarcity & Drought (EN WSD), with members of the existing Drafting Group on WS&D supplemented by additional non-represented MS and stakeholders, charged to support the Commission's further analysis and data collection. Following the outcomes of the Water Directors' meeting, Member States (MSs) called for EU action on WS&D from the Environment Council (held on 27/06/2006). It was proposed to include the specific aspects of WS&D in the CIS work programme 2007-2009, and a relevant work mandate for the EN WSD for the period 2007-2009 has been established. The EN WSD mandate concerns two main tasks: (a) support the in-depth assessment, building on the 1st Interim Report, by providing complementary data analysis (definition of indicators, data collection and analysis, synthesis of the information, gap analysis of the EU legislation and financial instruments), (b) support specific aspects of the implementation of the WFD linked to WS&D: analysis of agricultural measures that could be utilized to address WS&D, understanding of 'prolonged droughts' - definitions of indicators and thresholds relevant to the WFD Article 4.6 on exemptions, links between the WFD Programmes of Measures and Drought Management Plans allowing compatibility with WFD Art. 13).
November 2006	The 1st Interim Report on WS&D in-depth assessment (EC, 2006[1]) was produced (and presented at the Water Directors Meeting on 30/11/2006), identifying the magnitude of the problems linked to WS&D and the size of the residual gaps in the implementation of EU existing policies. Various stakeholders (EEA, Eurostat, JRC, Plan Bleu, etc.) and MSs supported the in-depth analysis and provided complimentary data, while the report was reviewed by the EN WS&D. The Water Directors also endorsed during their meeting on 30/11/2006, the mandate of the Expert Network on Water Scarcity and Droughts for the period 2007-2009, led by FR, IT, ES.

[1] EC, 2006. Water Scarcity and Drought First Interim Report, November 2006.

April 2007	The Mediterranean Water Scarcity & Drought Working Group (MED WS&D WG) of the MED JP WFD/EUWI produced a Technical Report on water scarcity and drought management in the Mediterranean and the Water Framework Directive (MED WS&D WG, 2007Error! Bookmark not defined.). The Expert Network on Water Scarcity and Drought (EN WS&D) produced a Report on "Prolonged Drought" (ENWSD, 2007a[2]), analysing the phenomenon and its impacts.
during 2007 Stakeholders' Meetings: 29/01/2007 26/03/2007 24/05/2007	Stakeholders' Consultation & Meetings: A consultation of all stakeholders concerned by WS&D issues was launched in early 2007. A Stakeholders' Forum has been set-up with comprehensive representation of all interested parties. 1st Meeting (29/01/2007): explain the process and report on the progress made so far with the in-depth assessment. Collect written contributions from stakeholders in order to improve the Interim Report and to propose possible orientations and measures. 2nd Meeting (26/03/2007): inform stakeholders about the state of play in preparing the EC Communication on WS&D and the improvements made to the in-depth assessment. Share all the contributions and identify possible measures that could be further considered within the Communication. 3rd Meeting (24/05/2007): review possible options. A broad consensus emerged from the meeting as to the need for an integrated approach which combines a strong emphasis on demand management, economic instruments – including more effective water pricing - and leaves the door open for new water supply under certain conditions.
June 2007	The 2nd Interim Report on WS&D in-depth assessment (EC, 2007b[3]) was produced. The conclusions of the 1st Interim Report (11/2006) pointed out the need to better assess the scope and the impacts of the WS&D issues. A second questionnaire was disseminated to all Member States in early 2007 in order to fill in the gaps identified by Member States and the Commission. The 2nd Interim Report updated the previous one on the basis of Member State replies to this questionnaire, and information provided by other DGs of the Commission, and was presented to the Water Directors on 18 June 2007 for discussion.
18/07/2007	Publication of the EU Communication on Water Scarcity and Drought (COM/2007/414 final) (EC, 2007a[4]), with its accompanying Impact Assessment (EC, 2007d[5])
October – November 2007	The Environmental Council of 30/10/2007 supported the Commission's 2007 Communication and invited the Commission specifically to review and further develop the WS&D policy by 2012. According to the EC Conclusions the Commission is invited to present a follow-up report in 2008, including deadlines for the implementation of the measures identified in the 2007 Communication and pursue the work on an EU strategy until 2012, thus guaranteeing Water Scarcity and Drought a place on the European environmental agenda.

[2] Expert Network on Water Scarcity and Drought (ENWSD), 2007a. "Prolonged drought" towards a common understanding of the phenomenon and of its impacts, Draft Report, April 2007.

[3] EC, 2007b. Water Scarcity and Droughts in-depth assessment, 2nd Interim Report. European Commission, DG Environment, Brussels, June 2007. Available online: http://ec.europa.eu/environment/water/quantity/pdf/comm_droughts/2nd_int_report.pdf

[4] EC, 2007a. Communication from the Commission to the Council and the European Parliament, Addressing the challenge of water scarcity and droughts in the European Union. Brussels, 18.07.07, COM(2007)414 final.

[5] EC, 2007d. Impact Assessment - accompanying document to the Communication from the Commission to the Council and the European Parliament Addressing the challenge of water scarcity and droughts in the European Union, Commission Staff Working Document, SEC(2007) 993, Brussels.

	The Water Directors endorsed, during their meeting on 29/11/2007, the EN WSD Report on Drought Management Plans (ENWSD, 2007b[6]). This Report set the basis for developing, when appropriate, drought management plans complementary to the River Basin management plans, aiming at minimizing the socio-economic and environmental WS&D impacts. The DMP Report recommends strategic, operative and administrative measures to be applied progressively, according to the drought status, which is previously identified through indicator systems.
December 2008	Publication of the 2008 Follow-up Report: The 1st Follow-up Report (EC, 2008[7]), accompanied by a Commission Staff Working Document, points to a number of areas (such as land-use planning, water pricing, water metering, promoting water efficient devices and practices, education, information and communication) which many Member States have already begun to address. However, it shows that more effort is needed in most of the areas and especially on drought risk management and the financing of water efficiency measures. The report is accompanied by a work programme. The implementation of the work programme will also be monitored and will be part of the review of the strategy for water scarcity and droughts.
November 2009	EG WSD Mandate 2010-2012: The Water Directors endorsed on 30/11/2009 the new mandate of the Expert Group on WS&D (EG WSD) for the the 2010-2012 CIS period, to address pending issues, requesting to deliver a set of common EU indicators for both drought and water scarcity. The aim of the follow-up process of the Expert Group is to provide pragmatic and simple indicators for both water scarcity and drought in order to provide a clear picture throughout the EU. The objective is to come up with a limited number of indicators for water uses, water availability etc. capturing both the natural phenomena and the socio-economic aspects. The indicators will be mainly built on the basis of case studies proposed by voluntary countries which reflect different climatic, socio-economic hydrologic conditions, and confronted and complemented by the existing indicators in other EU countries.
April 2010	On 27th April 2010, a Stakeholder Meeting took place, including the presentation of a non-paper (EC, 2010a[8]) presenting the planned studies and projects (building blocks), comments, and discussion on the main potential aspects of the Policy Review.
May 2010	Publication of the 2009 Follow-up Report: The 2nd Follow-up Report, (EC, 2010b[9]), accompanied by a Commission Staff Working Document, concluded that the priorities of the 2007 Communication on WS&D remain valid in spite the fact that the year 2009 has brought a certain hydrological relief, and that much more effort is needed to stop and reverse the process of overexploitation of Europe's limited water resources. It stresses the Commission's concern about the delay in the implementation of the WFD in the Member States having most of the worst-affected river basins in terms of water scarcity. In 2010 the focus will be on water efficiency and in particular the potential for savings in the water use of buildings, leakage reduction and the launch of the preparatory activities for the 2012 water scarcity and droughts policy review. The report is accompanied by a staff working

[6] Expert Network on Water Scarcity and Drought (ENWSD), 2007b. Drought Management Plan Report, including agricultural, drought indicators and climate change aspects, October 2007.

[7] EC, 2008. Report form the Commission to the European Parliament and the Council, First Follow up Report to the Communication on water scarcity and droughts in the European Union, Brussels, 19.12.2008, COM(2008) 875 final. Accompanied by a Commission Staff Working Document.

[8] EC, 2010a. Water Scarcity & Droughts – 2012 Policy Review – Building blocks Non-Paper

[9] EC, 2010b. Report form the Commission to the European Parliament and the Council, Second Follow up Report to the Communication on water scarcity and droughts in the European Union COM (2007) 414 final, Brussels, 18.05.2010, COM(2010)228 final. Accompanied by a Commission Staff Working Document.

	document presenting the follow-up of the work programme and further details on activities carried out by the European Institutions and Member States.
June 2010	In June 2010, the Environmental Council recognised that WS&D are already serious problems in many European regions and invited the Member States to promote more efficient and sustainable water use and recalled that trustworthy data would be needed on WS&D events to support further policy development. The Council invited the Commission to consider the right mix of measures and financial instruments needed to tackle WS&D events and to present relevant proposals as appropriate.
March 2011	Publication of the 2010 Follow-up Report: In the run up to a major water policy review in 2012, the 3rd Follow-up Report, (EC, 2011a[10]), accompanied by a Commission Staff Working Document, presents the water management measures introduced by Member States to tackle water scarcity and droughts and highlights the areas for further action. The report confirms that water scarcity and drought is not limited to Mediterranean countries. Apart from some sparsely-populated northern regions with abundant water resources, this is a growing issue across the EU. The Commission will further address this growing challenge in a review of EU water scarcity and drought policy which will form part of the Communication "Blueprint for safeguarding Europe's waters" scheduled for 2012. The report is accompanied by a staff working paper on the details of the activities carried out in the Member States.
2012	A prototype of the European Drought Observatory (EDO [11]) has been developed and interoperability arrangements have been established with key data centers at European, regional and local level. EU wide drought indicators have been developed on a preliminary basis for precipitation, soil moisture, vegetation response and a combined drought indicator targeted to agricultural drought. Further developments are required to test and improve the indicator set, to add further data from national and river basin level, to test and implement medium to long range drought forecasting and to perform hazard and risk analysis.
14/11/2012	2012 WS&D Policy Review: The Environmental Council of 30/10/2007 supported the Commission's 2007 Communication and invited the Commission specifically to review and further develop the WS&D policy by 2012. A Report on the review of the European WS&D Policy (EC, 2012b [12]), accompanied by a Commission Staff Working Document and additional background documents, has been published on 14/11/2012. This review has been carried out on the basis of the follow-up reports, studies and other information available, as well as the participation of stakeholders. The review of the Strategy for WS&D has been integrated into the EU Communication "Blueprint to safeguard European waters" (EC, 2012a[Error! Bookmark not defined.]), also published on 14/11/2012.
December 2012	In their meeting of 09/12/2012 the Water Directors endorsed two indicators (SPI and FAPAR), proposed the EG WSD, to illustrate drought events as elements of the future water scarcity and drought indicator system. The Standardized Precipitation Index (SPI) indicates meteorological drought and FAPAR (Fraction of Absorbed Photosynthetically Active Solar Radiation) indicates vegetation response to drought. Further technical drafting and testing of the remaining drought indicators

[10] EC, 2011a. Report from the Commission to the European Parliament and the Council, Third Follow up Report to the Communication on water scarcity and droughts in the European Union COM (2007) 414 final, Brussels, 21.03.2011, COM(2011) 133 final. Accompanied by a Commission Staff Working Document.

[11] The European Drought Observatory (EDO) http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000

[12] EC, 2012b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Report on the Review of the European Water Scarcity and Droughts Policy, COM(2012) 672 final. Accompanied by a Commission Staff Working Document (SWD/2012/380) and additional background documents.

	as well as in particular of the water scarcity indicator (WEI+) was encouraged.
June 2012	In their meeting of 04/06/2012 the Water Directors endorsed the "Water Exploitation Index+ (WEI+)" indicator, proposed by the EG WSD as part of the overall indicator set for water scarcity and drought, with the understanding that thresholds still need to be tested and agreed.
May 2013	The Water Directors endorsed on 31/05/2013 the CIS Work Programme for the period 2013-2015, which included the establishment of a Working Group on Water Accounts following-up on the work of the EN WS&D.
May 2015	The WG on Water Accounts drafted a Guidance Document on the application of Water Balances for supporting the implementation of the WFD (WG WA, 2015 [13]), which was endorsed by the Water Directors on 27/05/2015.The main objective of this Guidance is to support the development and use of water balances at the river basin and/or catchment scales in the context of the WFD implementation, as pre-requisite to sound and sustainable quantitative management of water resources

[13] Working Group on Water Accounts (WG WA), 2015. Guidance Document on the application of water balances for supporting the implementation of the WFD, April 2015.

Table A1.2: Policy options presented in the EC 2007 Communication on WS&D, and progress made towards their achievement.

Policy Option	Recommended way forward (EC, 2007a Error! Bookmark not defined.)	Progress made according to the 2012 WSD Policy Review (EC, 2012b)
1. Putting the right price tag on water	- Put in place water tariffs with incentives to use water resources efficiently - Apply 'user pays' principle - Introduce compulsory metering programmes in all sectors - Achieve cost recovery	Limited implementation of the cost-recovery and incentive pricing requirements has taken place. In agriculture, the biggest consumptive sector for water in the EU, operational costs for the provision of water are only partly recovered for 10 Member States and capital costs are often subsidized. An important share of water abstractions for agriculture in the EU is not priced, even in water stressed areas.
2. Allocating water and water-related funding more efficiently *a. Improving land-use planning*	- Increased emphasis on sustainable agriculture - Assess the inter-linkages between biofuel development and water availability - Ensure implementation of the Directive on SEA in all economic sectors - Identify river basins facing water stress and set up appropriate regulations to restore a sustainable water balance - Promote voluntary schemes, introduce compulsory measures on water saving & efficiency in very sensitive areas	Adapting land use to reduce the vulnerability of water resources is not common at MS level. Highly fragmented support actions and technical measures are promoted instead of integrated land and water use planning. Authorization procedures for water abstraction or use are in place in the MSs, but illegal abstractions remain an important challenge in parts of Europe. Water restrictions in times of WS&D are included in many national water allocation policies. Ecological flow schemes are increasingly used as an element of water allocation.
b. Financing water efficiency	- Refine existing Community strategic guidelines for water infrastructures in the context of the regional and rural development policies - Explore how sectoral policies could better contribute to effective water management utilising associated funds to foster the delivery of environmental services - Ensure efficient use of EU and national funds to improve water demand management through measures of	Progress has been made in integrating water quantity aspects into the Common Agriculture Policy (CAP). The Commission has proposed for the CAP to include the WFD in cross compliance, and to establish conditionalities for the use of Rural Development Funds for irrigation projects. The Commission has proposed to set efficient water supply and demand management for as key actions of the ERDF and Cohesion Fund investments into water management in 2014-2020, and a Communication (EC, 2011b [14]) has been published.

[14] EC, 2011b. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Regional policy contributing to sustainable growth in Europe 2020 (COM/2011/17 final).

	adaptation, sustainable practices, more water savings, monitoring systems and adapted risk management tools - Develop fiscal incentives for the promotion of water-efficient devices and practices	The use of EIB funds for MSs actions to address WS&D is still low. Cost-effectiveness and cost-benefit analysis has seldom been used by Member States to prioritize investments under the RBMP process.
3. Improving drought risk management *a. developing DRM Plans;*	- Foster exchange of best practices on Drought Risk Management - Identify methodologies for drought thresholds and drought mapping - Set up specific DMPs to supplement WFD RBMPs	The development of DMPs has progressed but their implementation and integration with RBMPs and other plans remains limited. Some measures in the RBMPs aim at reducing water abstraction, and can contribute to reducing vulnerability to drought; however they are mainly focussing on addressing water scarcity.
b. developing an Observatory and an early warning system on droughts	- Develop prototypes and set up implementing procedures for operational EDO and early warning system by 2012	A prototype of the European Drought Observatory (EDO) has been developed. EU wide drought indicators are available on a preliminary basis for precipitation, soil moisture, vegetation response and a combined agricultural drought indicator. Further developments are required to test and improve the indicators, to add further data, to drought forecasting, and to perform hazard and risk analysis.
c. further optimising the use of the EU Solidarity Fund and European Mechanism for Civil Protection	- Reiterate the EC's readiness to examine any request for EUSF support communicated by a MS and ensuring that it is not due to inefficient water management - Examine whether progress needs to be made in the context of the EUSF regulation - The Mechanism for Civil Protection will consider all opportunities to incorporate drought issues in future annual work programmes - The Civil Protection Expert Group on Early Warning Systems will be requested to develop an approach to optimise the use of the drought early warning system at European and national levels, and to anticipate any civil	Limited progress has been made with the use of EU Solidarity Funds in the area of droughts. The financing mechanism was activated once only for the 2008 Drought in Cyprus. Application rules are currently being revised.

	protection preparatory action	
4. Considering additional water supply infrastructures	- Prepare a EC assessment of all alternative options by the end of 2008 - Ensure that all adverse effects related to any additional water supply infrastructure are taken into account in the environmental assessment - Consider the changes expected as a consequence of climate change	In some MSs, additional water supply infrastructures have been developed before exploiting the full potential of water saving measures, thus in spite of the water hierarchy. The potential environmental impacts of new water supply infrastructure plans have not been systematically considered by MSs. The development or upgrade of desalinization plants is only presented in a few RBMPs but is of high importance for River Basins in Southern Europe. Adverse environmental effects of desalination are not always sufficiently considered in the plans.
5. Fostering water efficient technologies and practices	- Consider developing standards and legislation for water-using devices, such as irrigation systems and other farm energy-using equipment, taps, shower heads, etc. - Include water efficiency criteria in performance standards for buildings when harmonising Life Cycle Assessments and Environmental Product Declarations - Consider developing a new Directive for water performance of buildings (taps, showers, toilets, rainwater harvesting, reuse of 'grey water') - Consider adopting of a performance indicator on the use of water, working towards the possible certification of all buildings of the European Institutions - Encourage enhanced research on adaptation of economic activities to WS&D, water efficiency and decision-making tools - Encourage the adoption of binding performances for new buildings and for public and private networks, with systems of fines for excessive leakage in the MSs - Develop voluntary agreements with all economic sectors that need water to develop more water-friendly products, buildings, networks and practices.	Although substantial water efficiency gains have been achieved in irrigated agriculture, improving irrigation schedules and modernizing technologies can still provide significant water savings. Uncertainty remains however on how water saving at the field level is effectively translated into overall water saving at the farm and river basin level (modernization has led in some cases to intensification or more area being cultivated rather than a decrease in water use). Efficiency margins are still significant in building, e.g. in relation to eco-design of taps and shower heads. In the EU there is a large diversity of the efficiency of drinking water supply systems. In some cases, water distribution systems with low water efficiency (high leakage rates) can be at their optimal economic efficiency level. There is a lack of coordination between the RBMPs and other plans (e.g. land use), which, together with the absence of supporting financing plans, severely hinders the implementation of water efficiency measures.
6. Fostering the emergence of a water-saving culture in	- Explore the possibility of launching an Alliance initiative on the efficient use of water - Encourage the inclusion of rules on water management in existing and future quality and certification schemes	MSs are implementing a broad spectrum of awareness raising activities to foster water saving, but other tools such as incentive pricing, financing mechanisms for water saving eco-designm water using appliances, etc. are not alwayssufficiently

Europe	- Explore the possibility of expanding existing EU labelling schemes whenever appropriate in order to promote water efficient devices and water-friendly products - Encourage the development of educational programmes, advisory services, exchange of best practices and large targeted campaigns of communication focused on water quantity issues	present. In the area of sustainable consumption, two main trends regarding food and agricultural product are emerging: labeling schemes with a focus on the water footprint of a product, and schemes that are focused on encouraging good water stewardship. Labeling on the basis of a water footprint is not currently recommended as most consumers don't have sufficient knowledge to interpret the info and unresolved issues on the reliability of data underlying the footprint remain. The European Water Partnership has developed the European Water Stewardship (EWS) scheme with the aim to promote efficient practices by key water users. Criteria for certification are closely linked with the main WFD requirements and the EWS can therefore be a useful tool to optimise water management at RB level.
7. Improve knowledge and data collection *a. a WS&D Information System throughout Europe*	- Present an annual EU assessment based on agreed indicators and data provided by MSs and stakeholders to the EC or to the European Environment Agency (EEA) - Fully exploit the Global Monitoring for Environment and Security (GMES) services for the delivery of space-based data and monitoring tools in support to water policies, land use planning, and improved irrigation practices	EU wide coverage and long-time series of water quantity data are not yet available, therefore, the basic step of identifying water scarce river basins remains a challenge. Streamlined data on state and pressures, impacts and effectiveness of responses to address WS&D still need improvement. Progress towards the application of common WS&D indicators has been made under the WFD CIS by the Expert Group on WS&D. Three indicators have been aggred: the SPI, the fAPAR, the Water Exploitation Index Plus (WEI+) .
b. research and technological development opportunities	- Disseminate and facilitate the use and exploitation of the results of research on WS&D issues - Explore, enhance and encourage research and technological activities in this area, including networking	Water scarcity and water use efficiency research is scattered within the 6th and 7th Framework Programmes and stronger efforts are required to develop synergies with MSs reasearch activities inter-alia on water savings and efficiency and to ensure appropriate coordination with policy needs. This is gradually being implemented in recently launched projects.

ANNEX 2

List of studies that applied drought vulnerability assessments in different areas

Table A2.1: Roadmap of EU policy actions and initiatives related to WS&D.

Title	Authors	Year	Scale	Location
Vulnerability of rural Sahelian Households to Drought: options for adaptation	Adepetu and Berthe 2007	2007	Subnational	Africa
Overview of the Colorado Drought Vulnerability Assessment by Sector-Methods, Results, Challenges and Opportunities	Aggett 2012; CWCB 2010	2012	Subnational	North America
A new approach to quantifying and comparing vulnerability to drought	Alcamo et al 2008 (based on 3 studies)	2008	Subnational	Europe
Mapping the vulnerability of crop production to drought in Ghana using rainfall,yield and socioeconomic data	Antwi-Agyei et al 2012	2012	National	Africa
Future drought impact and vulnerability - case study scale	Assimacopoulos et al 2014	2014	Subnational	Europe
Vulnerability to drought cyclones and floods-India	Bhattacharya and Das 2007	2007	Subnational	Asia
Identification of Agricultural Drought Vulnerable Areas of Tamil Nadu, India—Using GIS Based Multi Criteria Analysis	Chandrasekar et al 2009	2009	Subnational	Asia
Fuzzy Comprehensive Evaluation of Drought Vulnerability Based on the Analytic Hierarchy Process	Cheng and Tao 2010	2010	Subnational	Asia
Methodological approach considering different factors influencing vulnerability – pan-European scale	De Stefano et al 2015	2015	Continental	Europe
Vulnerability of rural communities in the Mediterranean region to climate change and water scarcity: the case of Cyprus	Deems 2010	2010	National	Europe
Mapping Drought Patterns and Impacts: A Global Perspective	Eriyagama et al 2009	2009	Global	World
Climate Adaptation – modeling water scenarios and sectoral impacts	Florke et al 2011	2011	Continental	Europe
Assessing Vulnerability to Natural Hazards: Impact-Based Method and Application to Drought in Washington State	Fontaine and Steinemann 2009	2009	Subnational	North America

Title	Authors	Year	Scale	Location
Vulnerability hotspots: Integrating socio-economic and hydrological models to identify where cereal production may decline in the future due to climate change induced drought	Fraser et al 2013	2013	Global	World
Village-level Drought Vulnerability Assessment Using Geographic Information System (GIS)	Ganapuram et al. 2013	2013	Subnational	Asia
The Vulnerability Assessment Method for Beijing Agricultural Drought	Huang et al 2014	2014	Subnational	Asia
Chapter 10. Methods for evaluating social vulnerability to drought	Iglesias et al 2007	2007	Regional	Mediterranean
Spatio-temporal assessment of vulnerability to drought	Jain et al 2015	2015	Subnational	Asia
An Analysis of Vulnerability to Agricultural Drought in China Using the Expand Grey Relation Analysis Method	Jiang et al 2012	2012	National	Asia
Drought Risk Reduction in the Northern Cape, South Africa	Jordaan 2012	2012	Subnational	Africa
Drought impacts archive and drought vulnerability index	Karavitis et al. 2011	2011	National	Europe
Assessment of drought hazard, vulnerability, and risk: A case study for administrative districts in South Korea	Kim et al. 2013	2013	National	Asia
Drought risk and vulnerability assessment; a case study of Baringo county, Kenya	Kipterer and Mundia 2014	2014	Subnational	Africa
Studies on assessment of vulnerability to drought	Kumar 2013	2013	Subnational	Asia
Assessing Vulnerability to Drought Based on Exposure, Sensitivity and Adaptive Capacity: A Case Study in Middle Inner Mongolia of China	Liu et al 2013	2013	Subnational	Asia
Quantitative Assessment and Spatial Characteristics of Agricultural Drought Risk in the Jinghe Watershed, Northwestern China	Long et al 2011	2011	Subnational	Asia
Estimation and mapping of drought vulnerability on the basis of climate, land use and soil parameters using GIS technique	Móring et al 2012	2012	Regional	Europe
A study on agricultural drought vulnerability at disaggregated level in a highly irrigated and intensely cropped state of India	Murthy et al 2015	2015	Subnational	Asia
Exploring drought vulnerability in Africa: an indicator based analysis to inform early warning systems	Naumann et al 2014, Dewfora project reports	2013	Continental	Africa
Integrating Hydro-Meteorological and Physiographic Factors for Assessment of Vulnerability to Drought	Pandey et al 2010	2010	Subnational	Asia
Drought Vulnerability in Croatia	Perčec Tadić et al 2014	2014	National	Europe

Title	Authors	Year	Scale	Location
Integrated assessment of smallholder farming's vulnerability to drought in the Brazilian Semi-arid: a case study in Ceará	Pereira et al 2014/ Pereira et al 2011	2014	Subnational	South America
Integrated Index for Assessment of Vulnerability to Drought, Case Study: Zayandehrood River Basin, Iran.	Safavi et al 2014	2014	Subnational	Asia
Developing a synthetic index of land vulnerability to drought and desertification	Salvati et al 2009	2009	National	Europe
Drought risk assessment in the western part of Bangladesh	Shahid and Behrawan 2008	2008	Subnational	Asia
Water-deficit based drought risk assessments in Taiwan	Shiau and Hsiao 2012	2012	Subnational	Asia
Typologies of crop-drought vulnerability: an empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961–2001)	Simelton et al 2009	2009	National	Asia
Drought Risk Vulnerability Parameters among Wheat Farmers in Mashhad County, Iran	Sookhtanlo et al 2013 /Khoshnodifar et al 2012	2013	Subnational	Asia
Vulnerability of Water Systems: A comprehensive framework for its assessment and identification of adaptation strategies	Stathatou et al 2014	2014	Subnational	South America
Micro-level Drought Vulnerability Assessment in Peddavagu basin, a Tributary of Krishna River, Andhra Pradesh, India	Sreedhar et al 2013	2013	Subnational	Asia
Drought vulnerability, coping capacity and residual risk: evidence from Bolangir District in Odisha	Swain		Subnational	Asia
Vulnerability to Agricultural Drought in Western Orissa: A Case Study of Representative Blocks	Swain and Swain 2011	2011	Subnational	Asia
Groundwater drought vulnerability/ Integrated mapping of groundwater drought risk in the Southern African Development Community (SADC) region	Villholth et al.2011/ Villholth et al.2013	2011	Regional	Africa
Assessing Vulnerability to Agricultural Drought: A Nebraska Case Study	Wilhelmi and Wilhite 2002	2002	Subnational	North America
Assessment on agricultural drought vulnerability in the Yellow River basin based on a fuzzy clustering iterative model	Wu (Di) et al 2013	2013	Subnational	Asia
China's regional vulnerability to drought and its mitigation strategies under climate change: data envelopment analysis and analytic hierarchy process integrated approach	Yuan et al 2013	2013	Subnational	Asia
Drought vulnerability assessment: The case of wheat farmers in Western Iran	Zarafshani et al 2012	2012	Subnational	Asia
Assessment of drought vulnerability of the Tarim River basin, Xinjiang, China	Zhang et al 2014	2014	Subnational	Asia

Title	Authors	Year	Scale	Location
Analysing Agricultural Drought Vulnerability at Sub-district level through Exposure, Sensitivity and Adaptive Capacity based Composite Index	Zhang et al 2016	2014	Subnational	Asia

ANNEX 3

Results of the urban and agricultural intervention curves in the Ali-Efenti basin

Table A3.1: Results of the “urban intervention curve”

WC	shower head	faucet	washing machine	dishwasher	RWH	GWR	cost (AEC) €/hh	Total Cost (AEC) mio €	% Saving
0%	0%	0%	0%	0%	0%	0%	- €	- €	0.0%
0%	0%	0%	0%	0%	0%	0%	- €	- €	0.0%
7%	8%	0%	0%	0%	0%	0%	3.21 €	0.22 €	2.3%
8%	8%	0%	0%	0%	0%	0%	3.31 €	0.22 €	2.4%
0%	32%	0%	0%	0%	0%	0%	3.70 €	0.25 €	6.6%
0%	38%	0%	0%	0%	0%	0%	4.31 €	0.29 €	7.7%
0%	47%	0%	0%	0%	0%	0%	5.35 €	0.36 €	9.6%
0%	55%	0%	0%	0%	0%	0%	6.31 €	0.43 €	11.3%
0%	67%	0%	0%	0%	0%	0%	7.66 €	0.52 €	13.7%
0%	75%	0%	0%	0%	0%	0%	8.59 €	0.58 €	15.4%
0%	83%	0%	0%	0%	0%	0%	9.41 €	0.64 €	16.8%
0%	94%	0%	0%	0%	0%	0%	10.67 €	0.72 €	19.1%
13%	94%	0%	0%	0%	0%	0%	14.76 €	1.00 €	20.4%
27%	94%	0%	0%	0%	0%	0%	19.23 €	1.31 €	21.9%
19%	88%	62%	0%	0%	0%	0%	27.80 €	1.89 €	23.8%
19%	100%	62%	0%	0%	0%	0%	29.17 €	1.98 €	26.3%
79%	94%	0%	0%	0%	0%	0%	35.45 €	2.41 €	26.9%
82%	100%	0%	0%	0%	0%	0%	37.39 €	2.54 €	28.7%
100%	100%	0%	0%	0%	0%	0%	42.92 €	2.92 €	30.4%
76%	100%	66%	0%	0%	0%	0%	48.18 €	3.27 €	32.4%
91%	100%	70%	0%	0%	0%	0%	53.26 €	3.62 €	34.0%
100%	100%	100%	0%	0%	0%	0%	62.05 €	4.22 €	36.9%
100%	100%	100%	9%	0%	0%	0%	72.40 €	4.92 €	37.4%
100%	100%	100%	18%	0%	0%	0%	82.59 €	5.61 €	38.0%
100%	100%	100%	26%	0%	0%	0%	90.71 €	6.16 €	38.4%
100%	100%	100%	26%	11%	0%	0%	102.49 €	6.97 €	38.7%
100%	100%	100%	26%	11%	0%	0%	102.95 €	7.00 €	38.7%
100%	100%	100%	37%	11%	0%	0%	114.85 €	7.80 €	39.4%

100%	100%	100%	63%	0%	0%	0%	132.08 €	8.98 €	40.4%
100%	100%	100%	61%	12%	0%	0%	142.02 €	9.65 €	40.7%
100%	100%	100%	73%	0%	0%	0%	143.05 €	9.72 €	41.0%
100%	100%	100%	89%	0%	0%	0%	160.62 €	10.92 €	41.9%
100%	100%	100%	89%	11%	0%	0%	172.45 €	11.72 €	42.2%
100%	100%	100%	89%	11%	0%	0%	173.11 €	11.76 €	42.3%
100%	100%	100%	100%	11%	0%	0%	185.07 €	12.58 €	42.9%
100%	100%	100%	100%	11%	0%	0%	185.36 €	12.60 €	42.9%
100%	100%	100%	89%	0%	11%	0%	199.48 €	13.56 €	43.1%
100%	100%	100%	89%	19%	9%	0%	214.16 €	14.55 €	43.6%
100%	100%	100%	100%	11%	11%	0%	224.03 €	15.22 €	44.1%
100%	100%	100%	100%	18%	9%	0%	227.29 €	15.45 €	44.2%
100%	100%	100%	89%	11%	20%	0%	244.20 €	16.59 €	44.5%
100%	100%	100%	100%	11%	20%	0%	256.43 €	17.43 €	45.2%
100%	100%	100%	100%	19%	20%	0%	266.64 €	18.12 €	45.5%
100%	100%	100%	89%	64%	11%	0%	282.16 €	19.17 €	45.7%
100%	100%	100%	100%	11%	30%	0%	290.10 €	19.71 €	46.3%
100%	100%	100%	89%	81%	11%	0%	303.11 €	20.60 €	46.3%
100%	100%	100%	100%	74%	11%	0%	306.26 €	20.81 €	46.7%
100%	100%	100%	89%	74%	19%	0%	320.64 €	21.79 €	46.9%
100%	100%	100%	100%	74%	20%	0%	339.51 €	23.07 €	47.7%
100%	100%	100%	89%	74%	29%	0%	359.88 €	24.46 €	48.2%
100%	100%	100%	100%	63%	29%	0%	360.07 €	24.47 €	48.5%
100%	100%	100%	100%	74%	30%	0%	372.17 €	25.29 €	48.8%
100%	100%	100%	100%	81%	29%	0%	381.94 €	25.96 €	49.1%
100%	100%	100%	100%	93%	30%	0%	396.63 €	26.95 €	49.6%
100%	100%	100%	89%	11%	63%	0%	396.82 €	26.97 €	49.6%
100%	100%	100%	100%	11%	63%	0%	409.25 €	27.81 €	50.2%
100%	100%	100%	100%	11%	63%	0%	409.26 €	27.81 €	50.2%
100%	100%	100%	100%	92%	37%	0%	422.37 €	28.70 €	50.4%
100%	100%	100%	89%	11%	74%	0%	437.05 €	29.70 €	50.9%
100%	100%	100%	100%	11%	74%	0%	448.20 €	30.46 €	51.4%
100%	100%	100%	100%	18%	72%	0%	451.55 €	30.69 €	51.5%
100%	100%	100%	89%	11%	81%	0%	462.30 €	31.42 €	51.7%
100%	100%	100%	91%	11%	82%	0%	465.44 €	31.63 €	51.9%
100%	100%	100%	89%	18%	83%	0%	479.07 €	32.56 €	52.2%
100%	100%	100%	100%	18%	83%	0%	490.78 €	33.35 €	52.8%
100%	100%	100%	89%	18%	91%	0%	505.58 €	34.36 €	53.1%
100%	100%	100%	100%	18%	93%	0%	524.43 €	35.64 €	53.9%
100%	100%	100%	100%	11%	100%	0%	541.06 €	36.77 €	54.5%
100%	100%	100%	90%	75%	83%	0%	554.20 €	37.66 €	54.6%
100%	100%	100%	90%	82%	83%	0%	562.87 €	38.25 €	54.8%
100%	100%	100%	91%	73%	92%	0%	584.12 €	39.69 €	55.6%

100%	100%	100%	89%	81%	93%	0%	593.75 €	40.35 €	55.8%
100%	100%	100%	80%	81%	100%	0%	609.05 €	41.39 €	56.1%
100%	100%	100%	80%	81%	100%	0%	609.16 €	41.40 €	56.1%
100%	100%	100%	89%	82%	100%	0%	621.38 €	42.23 €	56.7%
100%	100%	100%	89%	82%	100%	0%	621.49 €	42.23 €	56.7%
100%	100%	100%	100%	81%	100%	0%	632.43 €	42.98 €	57.3%
100%	100%	100%	100%	100%	100%	0%	659.76 €	44.83 €	58.2%
100%	100%	98%	100%	98%	100%	6%	683.40 €	46.44 €	58.2%
100%	100%	100%	100%	99%	100%	8%	700.93 €	47.63 €	58.5%
100%	100%	100%	100%	102%	100%	13%	722.42 €	49.09 €	58.7%
100%	100%	100%	100%	99%	100%	16%	737.51 €	50.12 €	58.9%
100%	100%	100%	100%	100%	100%	17%	744.76 €	50.61 €	58.9%
100%	100%	100%	100%	101%	100%	20%	756.52 €	51.41 €	59.0%
100%	100%	100%	100%	99%	100%	24%	767.03 €	52.12 €	59.1%
100%	100%	100%	100%	100%	100%	28%	786.65 €	53.46 €	59.3%
100%	100%	100%	100%	98%	100%	29%	796.01 €	54.09 €	59.4%
100%	100%	100%	100%	98%	100%	33%	813.37 €	55.27 €	59.6%
100%	100%	100%	100%	99%	100%	36%	826.75 €	56.18 €	59.7%
100%	100%	100%	100%	99%	100%	39%	840.15 €	57.09 €	59.8%
100%	100%	100%	100%	98%	100%	41%	846.91 €	57.55 €	59.9%
100%	100%	100%	100%	99%	100%	44%	856.78 €	58.22 €	60.0%
100%	100%	100%	100%	99%	100%	46%	864.91 €	58.78 €	60.1%
100%	100%	100%	100%	99%	100%	48%	880.70 €	59.85 €	60.2%
100%	100%	100%	100%	98%	100%	52%	895.56 €	60.86 €	60.3%
100%	100%	100%	100%	98%	100%	52%	896.49 €	60.92 €	60.3%
100%	100%	100%	100%	98%	100%	55%	909.16 €	61.78 €	60.5%
100%	100%	100%	100%	99%	100%	57%	918.08 €	62.39 €	60.5%
100%	100%	100%	100%	99%	100%	61%	936.63 €	63.65 €	60.7%
100%	100%	100%	100%	99%	100%	61%	936.82 €	63.66 €	60.7%
100%	100%	100%	100%	101%	100%	10%	957.06 €	65.04 €	60.8%
100%	100%	100%	100%	100%	100%	10%	967.66 €	65.76 €	61.0%
100%	100%	100%	100%	102%	100%	9%	977.68 €	66.44 €	61.0%
100%	100%	100%	100%	99%	100%	9%	990.44 €	67.31 €	61.2%
100%	100%	100%	100%	101%	100%	20%	1,003.73 €	68.21 €	61.3%
100%	100%	100%	100%	101%	100%	19%	1,008.57 €	68.54 €	61.3%
100%	100%	100%	100%	100%	100%	18%	1,025.43 €	69.68 €	61.5%
100%	100%	100%	100%	99%	100%	18%	1,035.28 €	70.35 €	61.6%
100%	100%	100%	100%	101%	100%	30%	1,051.89 €	71.48 €	61.7%
100%	100%	100%	100%	101%	100%	30%	1,051.89 €	71.48 €	61.7%
100%	100%	100%	100%	99%	100%	26%	1,068.79 €	72.63 €	61.9%
100%	100%	100%	100%	98%	100%	27%	1,086.92 €	73.86 €	62.1%
100%	100%	100%	100%	98%	100%	27%	1,088.07 €	73.94 €	62.1%
100%	100%	100%	100%	101%	100%	39%	1,101.75 €	74.87 €	62.2%

100%	100%	100%	100%	99%	100%	40%	1,112.15 €	75.58 €	62.3%
100%	100%	100%	100%	98%	100%	35%	1,125.50 €	76.48 €	62.5%
100%	100%	100%	100%	98%	100%	31%	1,129.86 €	76.78 €	62.5%
100%	100%	98%	100%	98%	100%	10%	1,154.58 €	78.46 €	62.5%
100%	100%	100%	100%	97%	100%	47%	1,158.56 €	78.73 €	62.8%
100%	100%	100%	100%	97%	100%	47%	1,158.56 €	78.73 €	62.8%

Table A3.2: Results of the "agricultural intervention curve" for Karditsa

hectares

Collective Close			Collective Open			Individual Close		Collective Close	Individual Close		
Drip	Sprinkler	Furrow	Drip	Sprinkler	Furrow	Drip	Sprinkler	PA*	PA*	Cost (euro)	Efficiency
386	600	0	515	2101	686	161	15970	0	0	0	0.754
397	602	0	773	1843	673	166	15965	4	14	103399.567	0.761
402	607	0	1087	1527	665	182	15949	15	30	228568.087	0.77
397	605	1	1224	1388	674	171	15960	1	17	263014.702	0.774
403	604	1	1441	1173	666	164	15967	4	25	342255.778	0.780
446	613	1	1479	1119	630	171	15960	67	78	412031.319	0.7840
415	614	1	1745	859	654	167	15964	20	61	470060.774	0.790
431	625	2	1820	779	630	202	15929	65	83	536827.332	0.793
400	622	1	2048	549	668	197	15934	72	93	590614.529	0.798
449	620	1	2070	537	610	208	15923	83	63	637227.673	0.801
454	625	2	2246	345	617	196	15935	79	87	702014.584	0.806
481	627	2	2301	303	574	194	15937	50	78	737221.882	0.808
527	624	3	2344	254	536	168	15963	131	61	785677.723	0.812
710	636	2	2155	433	352	208	15923	68	102	871556.836	0.815
606	646	1	2356	205	475	351	15780	292	180	963963.341	0.818
751	634	1	2369	227	305	212	15919	91	91	979323.655	0.822
847	634	1	2373	235	197	213	15918	173	63	1060838.96	0.827
883	656	4	2416	167	163	218	15913	358	141	1156289.64	0.832
879	638	2	2393	215	160	452	15679	230	442	1246250.87	0.833
912	659	4	2433	148	131	309	15822	682	267	1287646.9	0.837
916	657	4	2425	166	119	411	15720	791	376	1357508.34	0.838
919	658	4	2432	161	113	521	15610	799	505	1422707.24	0.84
920	660	4	2437	150	117	604	15527	784	571	1462633.08	0.841
926	661	4	2439	148	111	762	15369	793	749	1552114.78	0.843
925	661	4	2439	147	113	945	15186	812	927	1644960.65	0.845
926	661	4	2439	146	112	1023	15108	783	965	1674401.17	0.846
923	659	4	2419	161	123	1246	14885	799	1175	1775626.7	0.848
926	662	4	2440	146	111	1228	14903	805	1212	1788637.89	0.849
915	661	4	2437	145	127	1532	14599	687	1378	1890566.69	0.85
925	661	4	2440	146	112	1752	14379	802	1685	2043174.13	0.854
927	661	4	2439	146	111	1852	14279	816	1792	2097134.38	0.855
927	662	4	2439	148	109	1959	14172	810	1953	2158670.4	0.857
927	661	4	2441	145	110	2249	13882	797	2142	2287305.58	0.859
925	662	4	2440	148	109	2314	13817	813	2255	2328778.71	0.861
926	662	4	2441	145	111	2425	13706	819	2391	2390142.78	0.862
927	662	4	2442	144	109	2544	13587	818	2532	2454399.02	0.864

927	663	4	2443	144	107	2615	13516	825	2608	2493237.7	0.865
926	662	4	2443	144	109	2739	13392	825	2727	2553670.88	0.866
923	662	4	2442	145	113	2908	13223	819	2893	2634282.63	0.868
926	662	4	2443	144	109	3076	13055	822	3067	2723360.2	0.87
916	660	4	2435	149	123	3263	12868	799	3247	2800194.53	0.871
927	662	4	2442	144	109	3455	12676	824	3443	2913723.64	0.874
926	662	4	2441	145	110	3628	12503	821	3574	2992901.26	0.876
926	662	4	2442	144	110	3776	12355	814	3755	3071798.51	0.877
926	662	4	2442	145	110	4016	12115	810	3922	3180061.31	0.88
927	662	4	2442	144	108	4329	11802	823	4303	3351786.23	0.884
923	661	4	2440	148	112	4488	11643	819	4410	3418106.2	0.885
925	662	4	2441	145	111	4715	11416	813	4662	3538302.1	0.888
923	662	4	2442	144	113	4804	11327	826	4765	3585601.67	0.889
926	662	4	2442	145	109	4900	11231	823	4867	3636923.93	0.89
926	662	4	2442	145	109	5305	10826	827	5282	3842839.8	0.895
926	662	4	2441	145	110	5508	10623	824	5485	3943438.97	0.897
927	663	4	2443	144	107	5748	10383	827	5710	4064224.96	0.9
927	662	4	2442	144	109	5908	10223	821	5883	4145250.34	0.902
925	662	4	2442	144	112	6023	10108	820	5998	4200852.69	0.903
927	662	4	2443	144	108	6128	10003	820	6085	4253419.61	0.904
928	662	4	2443	145	107	6385	9746	829	6371	4388919.32	0.907
926	662	4	2439	146	111	6606	9525	824	6454	4474791.27	0.908
926	662	4	2443	144	109	6764	9367	821	6656	4562360.4	0.911
927	662	4	2443	145	107	6982	9149	831	6951	4686792.99	0.914
928	662	4	2444	144	107	7128	9003	826	7081	4757399.42	0.915
926	662	4	2443	144	108	7336	8795	830	7311	4865084.46	0.918
924	662	4	2442	144	111	7549	8582	809	7460	4956954.78	0.919
928	662	4	2444	144	107	7773	8358	828	7749	5085523.93	0.923
925	663	4	2443	144	110	7925	8206	821	7908	5160069.82	0.924
927	662	4	2443	144	108	8057	8074	826	7986	5220420.15	0.926
928	661	4	2440	145	110	8237	7894	825	8199	5314805.73	0.928
926	662	4	2444	143	109	8483	7648	828	8340	5422968.99	0.93
928	662	4	2443	144	107	8674	7457	827	8606	5531989.9	0.933
926	662	4	2443	145	108	8860	7271	828	8802	5626035.8	0.935
925	662	4	2444	144	109	9126	7005	824	9066	5758460.62	0.938
926	662	4	2442	144	110	9306	6825	829	9245	5849367.73	0.94
928	663	4	2443	143	107	9398	6733	831	9363	5902506.68	0.941
925	662	4	2442	145	110	9553	6578	822	9520	5976457.62	0.943
927	663	4	2443	145	106	9719	6412	832	9705	6066822.18	0.945
929	663	4	2443	143	106	10031	6100	835	9992	6221640.15	0.948
928	662	4	2444	143	106	10141	5990	834	10110	6277439.11	0.949
928	663	4	2442	144	107	10393	5738	830	10260	6387046.08	0.952
928	663	4	2443	143	107	10434	5697	834	10404	6424835.34	0.953

928	662	4	2443	144	106	10609	5522	830	10570	6510553.01	0.955
927	662	4	2443	144	107	10914	5217	830	10872	6663365.51	0.958
928	662	4	2444	144	106	11216	4915	834	11193	6818991.35	0.962
928	662	4	2444	144	106	11583	4548	829	11555	7001996.16	0.966
924	663	4	2441	146	109	11734	4397	831	11688	7072733.65	0.967
929	663	4	2443	143	105	11842	4289	838	11809	7134244.07	0.969
928	663	4	2444	144	105	12023	4108	838	12003	7226592.29	0.971
929	663	4	2444	143	105	12296	3835	838	12274	7364757.73	0.974
929	664	4	2444	143	105	12351	3780	839	12333	7393091.02	0.975

Table A3.3: Results of the "agricultural intervention curve" for Trikala

hectares

Collective Close			Collective Open			Individual Close		Collective Close	Individual Close		
Drip	Sprinkler	Furrow	Drip	Sprinkler	Furrow	Drip	Sprinkler	PA*	PA*	Cost (euro)	Efficiency
1430	8578	0	0	0	204	3825	13563	0	0	0	0.776
1475	8575	0	1	27	135	3858	13531	21	129	71533.93	0.778
1460	8573	1	1	25	153	3834	13555	109	577	134814.1	0.78
1524	8571	1	1	25	90	3863	13525	114	866	238264.4	0.784
1526	8568	2	1	19	96	3851	13537	188	1422	332460.8	0.787
1545	8561	3	1	19	83	3860	13528	281	1880	433185.4	0.79
1625	8483	2	1	17	83	3927	13461	513	1905	524611.4	0.791
1550	8532	2	2	24	102	3875	13513	644	2693	614932	0.794
1551	8541	3	2	18	98	3859	13529	291	3170	631652.4	0.796
1649	8518	3	2	17	22	3849	13539	843	3198	783502.7	0.801
1617	8522	3	2	11	57	3877	13512	1013	3432	832742.6	0.802
1642	8506	3	2	10	49	3922	13467	1442	3475	933830.3	0.804
1739	8439	4	3	10	17	3960	13429	1346	3614	1000813	0.806
1668	8504	5	3	9	23	4224	13164	1544	3927	1145518	0.809
1684	8499	5	3	10	11	4497	12892	1535	4144	1282667	0.811
1729	8452	6	3	8	14	4632	12757	1465	4484	1386429	0.813
1738	8445	5	3	9	12	4967	12422	1574	4926	1592298	0.817
1771	8415	5	3	8	9	5147	12242	1631	5103	1704409	0.819
1765	8421	6	3	8	9	5286	12102	1662	5221	1773841	0.82
1763	8422	6	3	9	9	5430	11959	1658	5307	1835340	0.821
1763	8423	5	3	9	8	5530	11858	1634	5493	1895925	0.822
1766	8420	6	3	8	9	5734	11655	1648	5707	2002955	0.824
1762	8424	6	3	9	9	5930	11458	1654	5860	2094619	0.825
1752	8434	5	3	10	9	6130	11258	1620	6085	2190071	0.827
1766	8419	5	3	9	10	6241	11148	1655	6166	2251246	0.828
1746	8438	6	3	10	9	6658	10730	1565	6558	2435985	0.831
1760	8426	6	3	8	8	6718	10670	1657	6647	2491106	0.832
1759	8427	6	3	8	10	6895	10493	1659	6749	2568001	0.833
1742	8443	5	3	8	10	6993	10396	1623	6943	2619921	0.834
1732	8452	4	3	8	12	7339	10050	1605	7284	2786256	0.837
1753	8432	6	3	10	8	7442	9947	1625	7387	2849541	0.838
1759	8425	6	3	8	11	7541	9847	1646	7507	2907693	0.839
1757	8428	6	3	9	9	7666	9723	1638	7619	2966763	0.84
1730	8455	4	3	9	11	7840	9548	1566	7789	3032589	0.841
1772	8414	6	3	8	9	7897	9491	1667	7848	3092989	0.842
1758	8427	6	3	10	7	8140	9248	1631	8099	3206553	0.844

1765	8421	6	3	8	9	8285	9103	1664	8219	3282714	0.845
1767	8419	6	3	8	9	8481	8907	1658	8449	3386270	0.847
1750	8436	5	3	8	10	8637	8752	1640	8595	3453785	0.848
1766	8419	6	3	8	10	8727	8661	1656	8681	3506884	0.849
1768	8418	6	3	8	9	8866	8522	1655	8821	3577438	0.85
1766	8420	6	3	9	9	8989	8399	1659	8946	3639733	0.851
1760	8426	6	3	8	9	9117	8271	1659	9075	3702038	0.852
1754	8432	6	3	8	9	9285	8103	1658	9227	3781739	0.853
1762	8425	6	3	8	9	9568	7821	1658	9525	3929444	0.856
1749	8438	6	3	8	9	9694	7694	1644	9653	3986377	0.857
1761	8425	6	3	8	9	9811	7577	1630	9777	4048375	0.858
1762	8424	6	3	7	10	9921	7467	1658	9889	4108775	0.859
1749	8436	6	3	8	10	10072	7316	1644	10009	4172929	0.86
1747	8438	6	3	9	9	10241	7147	1617	10149	4248530	0.861
1754	8431	6	3	8	10	10422	6966	1632	10370	4350740	0.863
1747	8439	6	3	7	10	10544	6845	1632	10500	4410618	0.864
1750	8435	6	3	9	9	10716	6673	1601	10622	4485730	0.865
1748	8438	6	3	9	9	10782	6607	1634	10730	4530232	0.866
1737	8447	5	3	8	13	10992	6397	1603	10859	4612597	0.867
1750	8435	6	3	9	8	11159	6230	1629	11109	4720070	0.869
1754	8432	6	3	9	8	11294	6095	1634	11241	4789327	0.87
1756	8429	6	3	7	10	11379	6010	1650	11326	4835048	0.871
1765	8421	6	3	8	9	11507	5881	1642	11463	4903370	0.872
1771	8415	5	3	7	11	11602	5786	1663	11559	4955549	0.873
1743	8437	6	3	8	15	11810	5578	1629	11698	5032904	0.874
1758	8428	6	3	7	10	12083	5305	1660	12037	5192949	0.877
1758	8428	6	3	8	9	12229	5159	1655	12188	5266495	0.878
1759	8427	6	3	7	10	12352	5037	1648	12299	5325465	0.879
1767	8418	6	3	8	9	12522	4867	1651	12403	5403497	0.88
1759	8427	6	3	8	9	12674	4715	1661	12633	5491370	0.882
1767	8418	6	3	8	9	12802	4586	1654	12751	5556206	0.883
1754	8432	6	3	8	9	12916	4472	1660	12876	5611421	0.884
1759	8428	6	3	8	9	13063	4325	1660	13013	5685648	0.885
1764	8422	5	3	8	9	13186	4202	1655	13124	5746952	0.886
1758	8428	6	3	8	9	13314	4074	1637	13264	5807901	0.887
1766	8420	6	3	8	9	13457	3932	1673	13411	5889155	0.888
1766	8420	6	3	7	9	13663	3726	1667	13617	5991643	0.89
1766	8420	6	3	8	9	14013	3375	1660	13955	6164756	0.893
1767	8420	6	3	8	9	14108	3281	1667	14061	6215534	0.894
1772	8415	6	3	7	8	14257	3132	1669	14191	6290112	0.895
1759	8428	6	3	8	8	14367	3022	1651	14314	6339721	0.896
1771	8415	6	3	9	8	14524	2864	1653	14436	6417782	0.897
1772	8414	6	3	7	9	14583	2805	1679	14537	6458690	0.898

1761	8425	6	3	7	9	14776	2613	1660	14729	6548606	0.899
1774	8413	6	3	7	9	14941	2448	1679	14889	6638343	0.901
1771	8416	6	3	7	9	15066	2323	1676	15019	6700558	0.902
1762	8425	6	3	8	8	15196	2193	1665	15148	6760955	0.903
1755	8431	6	3	7	10	15333	2055	1650	15279	6823631	0.904
1767	8419	6	3	7	9	15431	1958	1663	15378	6879824	0.905
1773	8414	6	3	7	9	15617	1771	1682	15569	6979296	0.906
1777	8411	6	3	7	8	15770	1619	1685	15721	7058028	0.908
1777	8411	6	3	7	8	15770	1619	1685	15721	7058028	0.908