FINAL REPORT

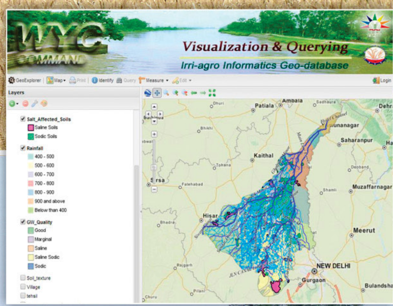
National Agricultural Innovation Project
(Indian Council of Agricultural Research)

भाकृअनुप
ICAR

राकृनप
NAIP

Component-1

Decision Support System for Enhancing Productivity in Irrigated Saline Environment Using Remote Sensing, Modelling and GIS



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CSSRI

Central Soil Salinity Research Institute

Zarifa Farm, Karnal 132001, Haryana, India

www.cssri.talents.co.in

2014

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Foreword

Dr. D.K. Sharma
Director and Consortia Leader
Central Soil Salinity Research Institute

A Sub-project '*Decision Support System for Enhancing Productivity in Irrigated Saline Environments using Remote Sensing, Modelling and GIS*' under component-1 of NAIP was operational at this institute from 2009 to 2014 which was implemented in the Western Yamuna Canal (WYC) system in Haryana- one of the oldest canal systems in the country by a consortia of three institutions led by CSSRI. The sub-project was unique by synerging the use of consortia mode for multi-institutions' participation, state-of-the-art geo-information technology, bottom-up approach in problem solving and modelling, and stakeholders' servicing for addressing the head-tail productivity difference in the WYC command. Despite of large variation in rainfall distribution, scarce canal supply by design and 62% area under marginal to poor quality groundwater in the command, wheat productivity has improved to 5.17 t ha^{-1} during 2011-12 against the national average of 3.18 t ha^{-1} using effective conjunctive use of canal and poor quality waters, and other inputs. Such intensification with ineffective conjunctive use has resulted in waterlogging and soil salinity affecting productivity. Therefore, sustainability of high productivity, and large head-tail productivity difference are two issues to be addressed.

During the past five years of its implementation, the sub-project has brought out many significant achievements and outcomes that have bearing on future course of canal database management system and its online sharing for identifying resource constraints at village/watercourse level, crop and salinity modelling, and development and deployment of DSS program for generating BMP based interventions for enhancing productivity in six saline environments (*water stagnation, waterlogging, soil salinity, soil sodicity, saline/sodic water irrigation* and *deficit irrigation)*. These achievements were amply demonstrated through innovative approaches in development of geospatial database and DSS program, field demonstrations, BMPs, and stakeholders' capacity building. The sub-project strongly believed in applications of ICT technologies as a tool for locating groundwater and soil quality constraints in mid and tail reaches and generating BMP based interventions under different scenarios for sustaining/improving crop productivity and minimizing head-tail yield difference in saline conditions. This strategy was ably blended with institutional interventions that involved in enhancing stakeholders' capacity on use of DSS program/ DSS generated BMPs.

CADA, Irrigation and Agriculture Departments, KVKs, WUAs and farmers in Haryana have learnt from the achievements and outcomes of this project to draw the message for adoption and future policy formulation in canal management and modernization, agricultural water management, and BMPs in saline environments. I also consider this project as a milestone in the area of ICT application in agricultural water management in canal commands and hope that the future projects and programmes will draw from the technologies/innovations generated and outcomes of this project. I congratulate the entire project team at three institutions for bringing out new learnings and compiling these results and outcomes in the form of the project report.

(Dr. D.K. Sharma)
Director and Consortia Leader

Karnal
24 March 2014

Preface

Dr. D.S. Bundela
Consortia Principal Investigator & Principal Scientist
Division of Irrigation & Drainage Engineering
Central Soil Salinity Research Institute

A sub-project '*Decision Support System for Enhancing Productivity in Irrigated Saline Environments using Remote Sensing, Modelling and GIS*' under Information Communication and Dissemination System sub-component of Component-1 of NAIP was implemented in the Western Yamuna Canal (WYC) command of Haryana between August 2009 and March 2014. The sub-project was aimed at locating bio-physical resource constraints and enhancing productivity and livelihoods of farmers in saline environments through application of Geo-IT, modelling, and crop production technologies to support innovative systems and processes in canal commands. The sub-project adopted holistic and participatory approaches, and implemented site-specific BMP based interventions generated through DSS application. The sub-project was unique by adopting consortia mode with CSSRI, WTC and NIH, advanced Geo-IT and bottom-up approach in problem solving and modelling. Despite being a Geo-IT driven sub-project, stakeholders' servicing was kept foremost in the sub-project for transfer of database, DSS program and knowledge for addressing the head-tail productivity difference.

The sub-project provided a flexible platform to attempt new and holistic approaches. A sound project implementation strategy involving project partners, state line departments, KVKs, canal WUAs, and farmers was responsible for achieving project desired results and outcome. The learnings in the sub-project have led to many insights, which have significant implications on research and policy formulation, especially in identifying resource constraints in canal commands by querying spatial database, predicting crop yield in saline conditions and implementing DSS program/DSS generated BMP interventions for enhancing productivity in six saline environments. It was also the sub-project that raised the issue of institutional capacity enhancement of all the implementing partners to deal with head-tail productivity difference and livelihoods in saline environment. In all, the project has delivered a new database and a DSS program, and capacity building of 121 state officers and 1194 WUA members and farmers.

On the behaf of project consortia, I express my sincere gratitude to Dr. D. Rama Rao, National Director (NAIP), and Dr. P.S. Pandey, National Coordinator (Component-1), NAIP for their constant support and encouragement throughout the period of project implementation. I also extend my sincere thanks to Dr. Mrithyunjaya, and Dr. Bangali Baboo, Ex-National Directors (NAIP), and Dr. N.T. Yaduraju and Dr. R.C. Agrawal, Ex-National Coordinators (Component-1) who guided the entire sub-project team in its formative and mid stages. I am deeply indebted to Dr. D.K. Sharma, Consortia Leader and Director, CSSRI, Dr. Gurbachan Singh, Ex-Director, Dr. S.K. Gupta, Ex-Acting Director and Dr. Ram Ajore, Ex-Acting Director, CSSRI, Dr. H.S. Gupta, Director, IARI and Dr. R.D. Singh, Director, NIH who supported the project teams during various stages of implementation and took keen interest in every aspect of the sub-project. The consortia leaders and partners reposed the confidence in the project team that has made significant strides. My sincere thanks are also due to all esteemed project partners, project scientists and project staff at CSSRI, WTC and NIH, who worked tirelessly for achieving the project results and outcome, and to all PIU-NAIP staff who provided the support for the project.

Karnal
28 March 2014

(D.S. Bundela)

Contents

Abbreviations

BMPs	Best Management Practices
CADA	Command Area Development Authority
CCPI	Consortia Co-Principal Investigator
CL	Consortia Leader
CP	Consortia Partner
CPI	Consortia Principal Investigator
CSSRI	Central Soil Salinity Research Institute
DSS	Decision Support System
EC	Electrical Conductivity
ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GCA	Gross Cultivated Area
GIS	Geographic Information System
GPS	Global Positioning System
Geo-IT	Geo-Information Technology
GR	Gypsum requirement
ICDS	Information Communication and Dissemination System
IT	Information Technology
ICT	Information and Communication Technology
IRS	Indian Remote Sensing
KVKs	Krishi Vigyan Kendras
LISS	Linear Imaging Self-Scanning System
NAIP	National Agricultural Innovation Project
NARS	National Agricultural Research System
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NIH	National Institute of Hydrology
PAD	Project Appraisal Document
PRA	Participatory Rural Appraisal
RSC	Residual sodium carbonate
WTC	Water Technology Centre
WYC	Western Yamuna Canal

सारांश

राष्ट्रीय कृषि नवोन्मेषी परियोजना (एन ए आई पी) के घटक–1 के उप–घटक आई.सी.डी.एस के अंतर्गत उप–परियोजना 'सुदूर संवेदन, मॉडलिंग एवं जी.आई.एस. के उपयोग से सिंचित लवणीय वातावरण में उत्पादकता बढ़ाने हेतु निर्णय सहायक तंत्र' का आरम्भ 21 अगस्त 2009 को केन्द्रीय मृदा लवणता अनुसन्धान संस्थान, करनाल के नेतृत्व में, जल प्रौद्योगिकी केंद्र, नयी दिल्ली एवं राष्ट्रीय जलविज्ञान संस्थान, रुड़की के साथ संयुक्त तत्वावधान में हुआ। यह परियोजना भारत के प्राचीनतम नहरी तंत्रों में से एक, हरियाणा की पश्चिमी यमुना नहरी (डब्ल्यू वाई सी) कमांड में अगस्त 2009 से मार्च 2014 तक कार्यान्वित की गयी। कमांड के अंतर्गत आने वाले 13,534 वर्ग किलो मीटर सकल कृषि प्रक्षेत्र को आठ जल सेवा प्रखंडों में बांटा गया जिसमें 5 जिले सम्पूर्ण रूप से (करनाल, पानीपत, सोनीपत, रोहतक, एवं झज्जर) एवं 7 जिले आंशिक रूप से (यमुनानगर, कुरुक्षेत्र, जींद, हिसार, भिवानी, रेवाड़ी एवं गुडगाँव) तथा 2205 गाँव शामिल है। इस उप–परियोजना का लक्ष्य सूचना और संचार प्रौद्योगिकी के अनुप्रयोगों के माध्यम से निर्णय सहायक तंत्र का निर्माण कर उचित प्रबंधन सूचनाओं से सिंचित लवणीय वातावरण में कृषक बंधुओं की फसल उत्पादकता बढाकर आय तथा आजीविका में वृद्धि करना है। इस उप–परियोजना में उन्नत सूचना प्रौद्योगिकी और भू–स्थानिक तकनीकों को अपना कर भागीदारी और समग्र दृष्टिकोण के द्वारा डेटाबेस का विकास, मॉडलिंग एवं निर्णय सहायक तंत्र (डी एस एस) के माध्यम से स्थान विशेष के लिए लवणीय वातावरण में कम फसल उपज के समाधान हेतु सुझाई गयी सर्वोत्तम प्रबन्धन प्रक्रियाओं (बी एम पी) का परिलक्षण कृषक बंधुओं के प्रक्षेत्र में प्रदर्शनों के माध्यम से किया गया है।

यह उप–परियोजना कई मायनों में अनूठी है क्योंकि इसका कार्यान्वयन एवं विकास कंसोर्टियम प्रणाली में होने से एक ओर तो भागीदार संस्थानों की विशेषज्ञता का लाभ मिला है वहीं दूसरी ओर विनियोगी समाधान एवं मॉडलिंग, अत्याधुनिक भू–स्थानिक प्रौद्योगिकी, मॉडलिंग तथा परियोजना भागीदारों के सहयोग से विकसित डी एस एस द्वारा सुझाई गयीं सर्वोत्तम प्रबंधन प्रक्रियाओं के सत्यापन हेतु लवणता/क्षारीयता एवं जलग्रस्त की समस्या से ग्रस्त बुटाना व झज्जर रजवाहों के अंतर्गत प्रायोगिक प्रक्षेत्र में सफल अनुपालन तथा बाद में इन्हीं प्रायोगिक प्रक्षेत्रों के प्रदर्शन, कार्यशालाओं एवं प्रशिक्षण के माध्यम से डी एस एस में विश्वास उत्पन्न किया गया। चुने गए रजवाहों के भागीदारों के साथ केद्रित समूह चर्चा, बुद्धिशीलता कार्यशालाएं, पी आर ए एवं प्रक्षेत्र दिवस के माध्यम से परामर्श श्रृंखलायें आयोजित की गयी। इन परामर्श श्रृंखलाओं से प्राप्त परिणाम आधारभूत सर्वेक्षणों से मानकीकृत किये गए और इस प्रकार चुने गए दोनों रजवाहों में स्थान विशेष गाँव के चयन द्वारा बीएमपी अपनाकर फसल उत्पादकता बढ़ाने का मार्ग प्रशस्त हुआ। यह उप–परियोजना बहु–संस्थानिक एवं बहु–विषयवस्तु आधारित होने के कारण एक आम रणनीति पर सहभागी संस्थान मिलकर कार्य किया ताकि तीनों जिलों के लवणीय/क्षारीय वातावरण में विभिन्न जैव–भौतिकीय संसाधनों एवं आजीविका का अन्वेषण कर कम फसल उत्पादकता जैसी जटिल समस्या के समाधान प्रस्तुत किये जा सकें। यही ध्यान रखते हुए उप–परियोजना के प्रारंभिक और कार्यकारी चरणों में परस्पर संवादात्मक गोष्ठियों, परामर्श और कार्यशालाओं का लक्ष्य प्राप्त कर लिया गया। उप–परियोजना की उपलब्धियों एवं परिणामों को निम्नलिखित आठ प्रमुख प्रसंगों के माध्यम से प्रस्तुत किया जा रहा है।

इर्री–एग्रो इन्फार्मेटिक्स डेटाबेस का विकास एवं ऑनलाईन प्रसार

पश्चिमी यमुना नहरी कमांड के जैव–भौतिकीय संसाधनों एवं सामाजिक आर्थिक संसाधनों का विकास इस परियोजना की पहली आवश्यकता थी, अतः सर्वप्रथम इरी–एग्रो भू–स्थानिक डेटाबेस का विकास किया गया और इसके लिए जीआईएस, उपग्रह सुदूर संवेदन, तथा जी पी एस उपकरणों का प्रयोग किया गया तथा प्रदेश समकक्ष विभाग और केंद्रीय संस्थानों से प्राप्त आंकड़ो व जानकारियों के विश्लेषण से 14 प्राथमिक मानचित्रों का निर्माण किया गया। वर्ष 2009 से 2013 तक इस डेटाबेस को वर्षा, नहरी जल उपलब्धता, भू–जल गुणवत्ता, लवणीय–क्षारीय मृदा, मृदा गठन, गाँव, रबी फसल, वाष्पोत्सर्जन, नहरी प्रवाह तथा उपग्रह सुदूर संवेदन से प्राप्त चित्रों द्वारा अन्वेषित सूचनाओ से प्रतिवर्ष अद्यतनः किया है। जी आई एस आधारित कार्यप्रणाली का विकास किया गया है। इसी अद्यतनः डेटाबेस से ही कम फसल उपज वाले क्षेत्र की पहचान की गयी है। इस जिओ–डेटाबेस में एकल/बहु मानदंडो जैसे मानसून वर्षा, नहरी जल उपलब्धता, भू–जल गुणवत्ता, लवणीय–क्षारीय मृदा, मृदा गठन, तथा गाँव की जानकारी के माध्यम से प्रश्न/क्वेरी द्वारा वांछित सूचना प्राप्त की जा सकती है। फसल उत्पादकता के अवरोधों की पहचान कर उनके स्थानिक विस्तार को जिलेवार चिन्हित कर लिया गया है। ये अवरोध जींद, सोनीपत, रोहतक एवं झज्जर जिलों में काफी बड़े भू–भाग में व्याप्त हैं। इन मापदंडों से प्राप्त संसाधन अवरोधों/प्रतिबाधाओं की जानकारी फसल उत्पादकता प्रतिक्रिया समीकरणों में इनपुट का कार्य करती है, जिससे लवणीय वातावरण में फसल उत्पादकता में नुकसान/कमी का आंकलन खेत स्तर पर किया जाता है। हालाँकि जिओ–डेटाबेस का विकास वस्तुतः इसरी आर्क जीआइएस– एक व्यवसायिक सॉफ्टवेर में किया गया था परन्तु इसकी लाइसेंस कीमत अत्यधिक होने के कारण वितरण में समस्या थी। मुफ्त वितरण के लिए क्वांटम जीआईएस सॉफ्टवेयर में इसका पुनर्विकास किया गया ताकि बिना किसी अतिरिक्त धन व्यय के सभी भागीदारों तक इसकी उपलब्धता सुनिश्चित की गयी और आगे इसे पोस्ट जीआईएस डाटाबेस संस्करण 2.0.3 तथा जिओसर्वर 2.3.0 में रूपांतरित किया गया है ताकि जिओ–डेटाबेस को ऑनलाइन भी देखा जा सके और गूगल मैप/अर्थ को आधार मानचित्र के तौर पर होने से अन्य मानचित्रों के साथ ही संसाधन प्रतिबाधाओं को वाटरकोर्स अथवा ग्राम स्तर पर पहचाना जा सकता है।

कमांड स्तर पर गेहूं उपज का उन्नयन

रबी अवधि वर्ष 2010–11 में तीन समयांतरालों पर सुदूर संवेदन से प्राप्त रिसोर्ससैट–1 लिस–3 उपग्रह मानचित्रों के अन्वेषण से प्राप्त समकालिक एन डी वी आई मानचित्रों से क्षेत्र स्तर तथा फसल के 290 कटाई आंकड़ो को कमांड स्तर तक बढाया गया। गेहूं उपज में अंतर को दर्शाने वाला मानचित्र जीआईएस द्वारा विकसित किया गया। औसतन उपज कमांड क्षेत्र में 3.51 से 4.75 टन प्रति हेक्टेयर रही। उच्चतम उपज 5.0 टन प्रति हेक्टेयर करनाल के इंद्री ब्लाक में दर्ज की गयी और सबसे कम उपज 2.30–3.50 टन प्रति हेक्टेयर रही जोकि सोनीपत, जींद, रोहतक, झज्जर, भिवानी एवं हिसार जिलों के 56% क्षेत्र में व्याप्त थी।

एक्वाक्रॉप और एस डब्ल्यू ए पी मॉडल द्वारा गेहूँ उपज एवं जड़ क्षेत्र लवणता का आंकलन

जल प्रवाह आधारित एक्वाक्रॉप और एस डब्ल्यू ए पी (SWAP) मॉडल का अंशांकन अन्न उपज, जल उत्पादकता और जड़ क्षेत्र लवणता के आंकलन हेतु तीन लवणता सहिष्णु गेहूं किस्मों (केआरएल–1–4,

19 तथा 210) तथा एक उच्च उपज गेहूं किस्म (एचडी–2894) और चार विभिन्न जल लवणता (1.5, 4, 8 एवं 12 डेसी सीमैन मीटर$^{-1}$) के लिए वर्ष 2009–10 के प्रायोगिक रबी फसल आंकडों के साथ किया गया तथा वर्ष 2010–11 के प्रायोगिक रबी फसल आंकडों के साथ सत्यापन किया। मॉडल की यथार्थता का मूल्यांकन करने के लिए मॉडल दक्षता (एम ई), एग्रीमेंट सूचकांक (डी) एवं डिटरमिनेशन सूचकांक (आर^2) की तुलना वास्तविक और प्रायोगिक परिणामों से की गयी। अंशांकित मॉडल के परिणाम एमई, डी एवं आर^2 (0.99) के लिए क्रमशः अन्न उपज, जल उत्पादकता एवं जल लवणता मूल्यांकन हेतु 0.27, 0.98 एवं 0.99 रहे। सत्यापित मॉडल के परिणाम एम ई, डी एवं आर^2 (0.99) के लिए क्रमशः अन्न उपज, जल उत्पादकता मूल्यांकन एवं जल लवणता हेतु 0.85, 0.96, एवं 0.94 रहे। हालाँकि, एक्वाक्रॉप मॉडल से प्राप्त परिणाम अन्न उपज के लिए सर्वोत्तम रहे, परन्तु सापेक्षिक रूप से जल लवणता, उच्च उपज के लिए कम यथार्थ रहे। जबकि,एस डब्ल्यू ए पी मॉडल से प्राप्त परिणाम अन्न उपज एवं जड़ क्षेत्र लवणता के लिए एक्वाकोर्प मॉडल सापेक्षिक रूप से अच्छे रहे। इस प्रकार दोनों मॉडल गेहूं की फसल में अन्न उपज के आंकलन में उपयोगी रहे। लवणीय जल सिंचाई एवं लवणीय मृदा वातावरण में अन्न उपज एवं जड़ लवणता समाधान हेतु एस डब्ल्यू ए पी मॉडलिंग ज्यादा उपयोगी होगी।

फसल जल मांग के अनुरूप नहर अनुसूचन

इरी–एग्रो इन्फार्मेटिक्स डेटाबेस से जीआईएस के माध्यम से झज्जर रजवाहे के मौसम, मृदा, फसल, एवं नहरी प्रवाह की स्थानिक विभिन्नता का आंकलन किया गया। इस जानकारी का प्रयोग इनपुट के तौर पर क्रोपवाट मॉडल संस्करण 8.0 में किया गया और रजवाहे के अंर्तगत बोये गए गेहूं और धान के लिए सिंचाई का आंकलन किया गया। क्रोपवाट मॉडल से वृद्धिकाल में गेहूं के लिए 254.6 मि मी तथा धान के लिए 969.6 मि मी सिंचाई की आवश्यकता का आंकलन खेत स्तर पर किया गया जबकि गेहूं व धान के लिए प्रभावशाली वर्षा क्रमशः 55.8 मि मी तथा 469.8 मि मी रही। आगे फसल–जल मांग और नहर आपूर्ति की तुलना अनुसूची के अनुसार डब्ल्यू वाई सी कमांड के झज्जर रजवाहे के 12 गाँव के लिए की गयी, और यह पाया गया कि 2011–12 की अनुसूची के अनुसार नहरी जल उपलब्धता अधिकांश स्थानों पर बहुत कम (<48%) है। इसके साथ ही डेटा अन्वेषण द्वारा सिंचाई हेतु जल आवश्यकता के मूल्यांकन के लिए विकसित प्रोटोकॉल को रजवाहे स्तर से बढाकर शाखा नहर एवं पूर्ण कमांड क्षेत्र में अथवा देश के किसी भी समान नहरी कमांड के लिए प्रयोग किया जा सकता है।

लवणीय सिंचित परिवेश में उत्पादकता वृद्धि हेतु एकल डी एस एस प्रोग्राम

इस उप–परियोजना के प्रमुख उद्देश्यों में एक कंप्यूटर आधारित निर्णय सहायक तंत्र (डी एस एस) एकल विंडो प्रोग्राम का निर्माण करना था जोकि लवणीय वातावरण में व्याप्त विभिन्न संसाधन प्रतिबाधाओं/अवरोधों के परिदृश्य में क्षेत्र स्तर पर फसल उपज में होने वाली संभावित गिरावट का आंकलन कर सके साथ ही फसल उपज बढ़ाने के लिए उचित बी एम पी सुझा सके तथा हरियाणा समकक्ष विभाग, कृषि विज्ञान केन्द्र, व विकासशील भागीदार जानकारी प्राप्त करने में इसका उपयोग कर सकें। माइक्रोसॉफ्ट विसुअल सी शार्प–नेट फ्रेमवर्क 3.5 में विकसित इस विंडो प्रोग्राम संस्करण 1.1 में 9 मॉड्यूल– डेटाबेस, फसल–जल मांग, नहरी–जल आपूर्ति, भू–जल, सिंचाई अनुसूचन, मॉडलिंग तथा बीएमपी आधारित रणनीतियां, कृषक सेवाएं व सहायता समाहित हैं। डेटाबेस मॉड्यूल आठ प्रमुख मानचित्रों तथा उनके

साथ संलग्न सूची के माध्यम से इरी–एग्रो सूचना डेटाबेस से क्वेरी द्वारा संसाधन प्रतिबाधाओं की जानकारी क्षेत्र स्तर पर उपलब्ध कराता है। फसल–जल मांग मॉड्यूल दैनिक मौसम आंकड़ों व एकल फसल गुणांक से पेन्मेन–मोंटीथ पद्धति द्वारा फसल जल मांग और सिंचाई आवश्यकता की गणना करता है विभिन्न क्षेत्रों में सिंचाई मांग वाटरकोर्स द्वारा आपूर्ति की मात्रा का आंकलन, प्रभावकारी वर्षा व मृदा कोशिका जलह्रास को घटाकर, बहाव व प्रयोग ह्रास को जोड़कर प्राप्त किया जाता है। नहरी जल मॉड्यूल नहरी जल आपूर्ति और सिंचाई में कमी का आकलन कर रबी अवधि के दौरान फसल के लिए वांछित जल की सम्पूर्ण आवश्यक मात्रा का परिकलन करता है वही भू–जल मॉड्यूल फसल की कुल आवश्यक सिंचाई मात्रा को पूरा करने में भू–जल के योगदान और इसकी गुणवत्ता का फसल उपज पर होने वाले प्रभाव का मापन करता है। सिंचाई अनुसूचन मॉड्यूल में तीन वैकल्पिक सिंचाई अनुसूचन प्रणालियों का मूल्यांकन अधिक फसल उपज के लिए नहरी जल व भू–जल के संयोजन व अपर्याप्त सिंचाई जैसी परिस्थियों में मृदा लवणता के प्रभाव को कम करने के सन्दर्भ में किया गया है। मध्यम से सीमित लवणीयता/क्षारीयता युक्त भू–जल के समुचित उपयोग के लिए चक्रीय नहर जल संयोजन के साथ उपयुक्त सिंचाई रणनीतियां जैसे विकल्पों का मूल्यांकन विभिन्न संसाधन अवरोधों में भी अच्छी उपज प्राप्त करने के लिए किया गया है।

चूंकि छह प्रमुख लवणता परिदृश्यों जैसे अल्पकालिक जलभराव, जलग्रस्तता, मृदा लवणता, मृदा क्षारीयता, लवणीय/क्षारीय जल सिंचाई एवं अपर्याप्त सिंचाई जोकि डब्ल्यू वाई सी कमांड क्षेत्र में व्याप्त हैं, एक फसल उपज मॉड्यूल इन्ही परिदृश्यों के सापेक्ष रबी अवधि की गेहूं की फसल उपज में गिरावट के आंकलन के लिए विकसित व सत्यापित किया गया है ताकि उपज में गिरावट कम करने हेतु नवीन बी एम पी सुझाई जा सकें। प्रक्षेत्रों से प्राप्त आंकड़ों द्वारा सारे मॉड्यूल सत्यापित किये गए हैं और सत्यापन के बाद ही इन्हें डी एस एस के अंतराफलक में सूचीबद्ध किया गया है। मात्रात्मक प्रभाव के मूल्यांकन के लिए प्रत्येक बी एम पी के बारे में सम्पूर्ण सूचना भी उपलब्ध करवाई गयी है। जल प्रौद्योगिकी केंद्र, न्यू दिल्ली द्वारा मृदा और जल लवणता में उपज बढ़ाने के लिए भी एक मॉड्यूल विकसित किया है जिसमें प्रक्षेत्र से प्राप्त आंकड़ो के आधार पर गेहूं की जड़ में फोलिअर पोटेशियम फर्टिलाइजेशन और लवणता जमाव का आंकलन किया गया है। यह मॉड्यूल भी डी एस एस के अंतराफलक में सूचीबद्ध है। कृषक सेवा मॉड्यूल के अंतर्गत मृदा व जल परीक्षण सुविधाएँ, लवणता सहिष्णु फसल व किस्में, उच्च उपज देने वाली फसलें, कृषि विभाग, काडा, कृषि विज्ञान केन्द्र से संपर्क हेतु करमुक्त दूरभाष क्रमांक, आपूर्तिकर्ता तथा लवणीय/क्षारीय परिस्तिथियों में सुझाई गयी बी एम पी आदि की जानकारी उपलब्ध हैं। डी एस एस को अधिक उपयोगी बनाने के लिए इसको हिंदी भाषा में पुनर्विकसित भी किया गया है ताकि यह परियोजना के भागीदारों से लेकर उपयोगकर्ताओं में भी लोकप्रिय हो सके। इसी क्रम में एकल डी एस एस के ऑनलाइन प्रतिरूपण विकसित करने के लिए प्रयास किये हैं, ताकि अधिक से अधिक भागीदारों तक इसकी पहुँच सुनिश्चित हो सके।

कृषक खेतों पर प्रक्षेत्र प्रदर्शन

बुटाना एवं झज्जर रजवाहे के अंतर्गत लवणता ग्रस्त परिवेश में 52 कृषक बंधुओं के खेतों में गेहूं की फसल के प्रायोगिक प्रदर्शन वर्ष 2010–11, 2011–12 एवं 2012–13 में सोनीपत, रोहतक एवं झज्जर में सुझाई गयी पाँच बी एम पी जिनमे 4 उच्च उपज किस्में (एचडी–2891, 2894, 2967 एवं डीबीडब्लू–17)

तथा 3 लवणता सहिष्णु किस्में (केआरएल–1–4, 19 एवं 210), मध्यम लवणीय और उच्च आर ए सी भू–जल के नहरी जल के साथ प्रभावी संयुक्त उपयोग, रेखीय बुवाई, इष्टतम सिंचाई समयबद्धन, लेसर द्वारा भूमि समतलीकरण तथा शून्य जुताई आधारित बुआई द्वारा फसल उत्पादकता में वृद्धि के मूल्यांकन हेतु प्रदर्शन आयोजित किये गए। लवणीय परिवेश में गेहूं की उपज में 17 से 33% तक की वृद्धि हुई जिससे ₹ 13,490–25,700 प्रति हेक्टेयर के हिसाब से कृषकों की आमदनी में भी वृद्धि हुई। इन दो रजवाहों में तीन वर्ष के रबी अवधि में किये गए प्रक्षेत्र प्रदर्शनों से कृषक बंधुओं के मन में डीएसएस द्वारा सुझाये गए सुधारों के प्रति विश्वास उत्पन्न हुआ और साथ ही डीएसएस मॉडुल्स का सत्यापन किया।

डेटाबेस, डी एस एस प्रोग्राम एवं जानकारियों का भागीदारों में हस्तांतरण

भागीदारों तक डी एस एस की सेवाओं की जानकारी हस्तांतरित करना इस परियोजना का एक प्रमुख उद्देश्य रहा है एवं परियोजना का 13% बजट का आबंटन इस हेतु हुआ है इसी को दृष्टिगत रखते हुए कमांड क्षेत्र विकास प्राधिकरण (काडा), कृषि विभाग, सिंचाई विभाग, कृषि विज्ञान केन्द्र, चौधरी चरण सिंह हरियाणा कृषि विश्वविद्यालय के क्षेत्रीय अनुसन्धान केंद्र एवं गैर सरकारी संगठन (एन जी ओ) आदि के 121 अधिकारियों/अभियंताओं को डी एस एस के उपयोग से बी एम पी द्वारा लवणीय वातावरण में उत्पादकता वृद्धि की जानकारी और संचालन हेतु कार्यशालाओं, प्रक्षेत्र दिवसों एवं प्रशिक्षण कार्यक्रमों का आयोजन किया गया। इसी प्रकार नहर जल उपयोग संघों के 1194 सदस्यों नहरी जल संघ सदस्यों एवं कृषक बंधुओं को 8 जिलों (करनाल, पानीपत, सोनीपत, जींद, रोहतक, झज्जर, रेवाड़ी एवं भिवानी) के डी एस एस में द्वारा सुझाई गयी बी एम पी के अनुपालन द्वारा लवणीय वातावरण की परिस्थितियों जैसे मृदा लवणता, निम्तम गुणवत्ता का भू–जल, अपर्याप्त नहरी जल, जलग्रस्तता एवं खराब मृदा उर्वरता में भी अधिकतम उत्पादकता वृद्धि करने के लिए जानकारी पहुंचाई गयी।

डी एस एस का उन्नयन

डी एस एस कंप्यूटर प्रोग्राम का अभिनियोजित करने एवं इसकी व्यवहारिकता के निर्धारण के लिए पानीपत, सोनीपत, रोहतक, झज्जर, रेवाड़ी, जींद व कैथल स्थित सात कृषि विज्ञान केन्द्रों में कंप्यूटर हार्डवेयर और सॉफ्टवेयर की उपलब्धता, इंटरनेट संयोजन, स्टाफ तथा जनरेटर के साथ बिजली आपूर्ति आदि पैमानों का मूल्यांकन किया गया। रोहतक में उचित स्टाफ का अभाव था, तो दूसरी ओर पानीपत, सोनीपत, एवं जींद में ग्रामीण बिजली संयोजन होने के कारण बिजली आपूर्ति काफी अनियमित पाई गयी। पानीपत, रोहतक एवं रेवाड़ी के कृषि विज्ञान केन्द्रों में मौजूद कम्प्यूटरों पर डी एस एस का परीक्षण किया गया और सहयोगी सेवाएं भी प्रदान की गयीं। करनाल, पानीपत, सोनीपत, रोहतक, जींद व कैथल के छह काडा खंड कार्यालयों में भी डी एस एस के परीक्षण हेतु वांछित संसाधनों की उपलब्धता पायी गयी। संस्थान कोष से बारहवी पंचवर्षीय योजना के अंतर्गत डी एस एस प्रोग्राम का अभिनियोजन जारी रहेगा, जिसमे काडा का सहयोग भी शामिल है। डी एस एस प्रोग्राम पर उपयोगकर्ताओं की प्रतिपुष्टि अत्यन्त उत्साहजनक रही है।

EXECUTIVE SUMMARY

The sub-project '*Decision Support System for Enhancing Productivity in Irrigated Saline Environments Using Remote Sensing, Modelling and GIS*' under ICDS sub-component of component-1 of NAIP was launched on 21 August 2009 by a Consortia of CSSRI, WTC-IARI, and NIH led by CSSRI. The sub-project was implemented between August 2009 and March 2014 in the Western Yamuna Canal (WYC) command of Haryana-one of the oldest canal systems in the country. The command is divided into 8 water service circles with gross cultivated area (GCA) of 13,534 km^2 covering 5 districts in full (Karnal, Panipat, Sonipat, Rohtak and Jhajjar), 7 districts in part (Yamuna Nagar, Kurukshetra, Jind, Hisar, Bhiwani, Rewari and Gurgaon) and 2205 villages. The sub-project was aimed at application of ICT for development of database and DSS program for making informed decision for improving crop yield, income and livelihoods of small farmers in six saline environments. Therefore, the sub-project has adopted the advanced Geo-IT with holistic and participatory approaches for database generation, distributed modelling and development of DSS program for generating and implementing site-specific BMP based interventions at farmers' fields to address the issue of head-tail productivity difference, low crop yield and income in saline environments in the WYC command.

The sub-project was unique in many ways by adopting a consortia mode for project development and implementation by utilizing institutions' expertises, bottom-up approach to problem solving, state-of-the-art Geo-IT, distributed modelling, and stakeholders' servicing to infuse confidence on the developed Database and DSS program through demonstrations, workshops and hands-on trainings to address the issues of head-tail productivity difference and sustainability of high yield in saline/sodic conditions under Butana and Jhajjar distributaries. A series of consultations with stakeholders from two selected distributaries was conducted by applying focused group discussions, brainstorming workshops, PRA, and field days. The output of these activities was supported by baseline surveys conducted in the selected villages in both distributaries to pave the way to implementing site specific BMP based interventions generated through DSS program. Since the sub-project was a multi-institute and multi-disciplinary addressing complex issue of head-tail difference in productivity and livelihoods in Butana and Jhajjar distributaries having diverse bio-physical and socio-economic constraints in saline environment, it was necessary to develop common strategies by all project partners. This was achieved through interactive meetings, discussions, and workshops during the initial and implementation phases of the sub-project. The achievements and outcome of the sub-project were grouped into eight major themes and are presented as follows.

Development and Online Dissemination of *Irri-agro Informatics* Spatial Database

An *Irri-agro Informatics Geodatabase* on bio-physical and socio-economic resources of the WYC command was developed using ArcGIS v10 from secondary source maps and data, satellite remote sensing data and GPS field surveys and is comprised of 14 key thematic layers viz. canal network with system and inflow characteristics, rainfall pattern, groundwater quality, salt-affected soils, soil texture, cropping system, terrain, waterlogging, land use, infrastructure, geology, socio-economic data, satellite data derived current land use, and digital cadastral data. The geodatabase, updated annually for the *rabi* crop, soil and water salinity, canal inflow and remote sensing data from 2009-2013, has characterized the bio-physical resources at entire command, district, tehsil, distributary, village, watercourse and farm levels. The characteristics of the WYC command are of 3 levels in canal network (main canal to watercourse) with system and inflow characteristics; 4 rainfall departure classes (excess, normal, deficient and scanty) during 2006-13; 6 rainfall zones - 18.6% area (<500 mm), 51.6% (500-600 mm), 17.3% (600-700 mm), 8.8% (700-800 mm), 1.6% (800-900 mm), 2.1% (>900 mm); 5 groundwater quality classes- good (38.3% area), marginal (15.2%), saline (5.3%), sodic (4.2%) and saline-sodic (37%); 2 salt-affected soils (SAS)- saline (4.0%), and sodic (14.5%); 4 soil texture classes- sand (2.4%), loamy sand (6%), sandy loam (78.6%), and loam (13%); and 5 cropping systems (rice-wheat, bajra-wheat/mustard, sorghum-wheat, cotton-wheat, and sugarcane-wheat). The *Geodatabase* can be queried for single or multiple attributes/ features using criteria such as monsoonal rainfall, adequacy of canal supplies, groundwater quality, saline/sodic soils, soil texture, village and other information and the district-wise crop production constraints and their spatial extent were identified. These constraints have prevailed in the large parts of Jind, Sonipat, Rohtak and Jhajjar districts which are input to crop-water-salinity-yield response model to predict the crop yield loss in six saline environments.

The geodatabase has also delineated the area of low productivity district-wise in the WYC command adopting a GIS protocol using data of canal supply, GW quality, SAS and NDVI. About 7.24% of the WYC command was affected with low productivity (988.9 km^2), mainly in Rohtak, Jind and Sonipat districts. The database originally developed in ESRI's ArcGIS proprietary format was migrated to an open source platform (Quantum GIS v1.7.4) which has allowed free distribution of the database and GIS software to the stakeholders for querying and generating value added maps. The database was further migrated to PostGIS v2.0.3 and GeoServer v2.3.0 for online dissemination and a web map service of the database was developed for online visualization and querying of multi-thematic vector layers overlaid with Google map/earth by stakeholders for identifying resource constraints at watercourse or village level.

Upscaling of Wheat Yield to Command Scale

The wheat yield data from 290 crop cutting samples collected from demonstration and monitoring fields in the WYC command using GPS handset and data from Agriculture Department, Haryana were correlated with the temporal NDVI spectral profile generated from three Resourcesat-1 LISS-3 imageries (19 Dec, 5 Feb and 11 Mar) for the rabi season 2010-11. These data were analysed using GIS in tandem with spectral vegetation, salinity and waterlogging indices (NDVI, NDSI and NDWI) and were upscaled to generate the map of wheat yield variation in the WYC Command using regression technique. The wheat yield ranged from 3.51 to 4.75 t ha^{-1}. The yield less than 4.0 t ha^{-1} was assessed in 56% area of the command which lies in parts of Sonipat, Jind, Rohtak, Hisar, Jhajjar and Bhiwani districts.

AquaCrop and SWAP Models for Predicting Wheat Yield and Salt Dynamics

Water driven AquaCrop model 4.0 with salinity option, and SWAP model were calibrated for grain yield, water productivity and rootzone salt dynamics for three salt tolerant (KRL-1-4, 19 and 210) and one high yielding (HD-2894) wheat varieties, and four water salinities (1.5, 4, 8 and 12 dS m^{-1}) from the experimental data of *Rabi* 2009-10 and were validated from the data of *Rabi* 2010-11. The accuracy of model prediction was evaluated by model efficiency (ME), index of agreement (d) and coefficient of determination (R^2) comparing between the observed and the model simulated results. The calibrated AquaCrop model resulted in ME, d and R^2 of 0.99 each for grain yield; and 0.27, 0.98 and 0.99 for water productivity, respectively, for all wheat varieties and irrigation salinity levels whereas the calibrated SWAP model resulted in ME and d of 0.96 and 0.99 for grain yield; and 0.76 and 0.93 for root zone salinity, respectively. The ME, d and R^2 for the validated AquaCrop model were 0.85, 0.96, and 0.94 for grain yield, respectively, for all varieties and salinity levels whereas the ME, d and R^2 for the validated SWAP model were 0.75, 0.93 and 0.95 for grain yield; and 0.95, 0.98, and 0.96 for root zone salinity, respectively. Therefore, both the models could predict the wheat yield with the acceptable accuracy for all wheat varieties and irrigation salinity levels. However, SWAP could simulate the root zone soil salinity more accurately. Therefore, both the models were integrated to DSS program and can be applied for prediction of wheat grain yield and rootzone salt dynamics in the WYC Command wherever site specific input parameters for these models are available. However, AquaCrop can be preferred for limited availability of site specific input parameters.

Crop Water Demand Driven Canal Schedule

The spatial variability of weather, soil, crop, canal network and inflow of Jhajjar distributary command was generated from the *Irri-agri informatics geodatabase* using GIS. These information were input to CROPWAT model 8.0 and the irrigation requirement of wheat and rice grown in the distributary command was estimated. The analysis indicated an area of 5601 hectares was under rice-wheat cropping system in the distributary. The irrigation requirement of wheat at field level by CROPWAT was 254.6 mm and that of rice was 969.6 mm with effective rainfall of 55.8 and 461.8 mm during the wheat and rice growing seasons, respectively. Further, the comparison of crop water demand and canal supply as per the roster for twelve locations in Jhajjar distributary in WYC command showed that the canal supply as per roster for 2011-12 is far less (< 48%) than the demand in majority of location points. Moreover, the protocols developed for assessment of irrigation requirement can be upscaled from distributary to branch canal command.

A Standalone DSS Program for Enhancing Productivity in Irrigated Saline Environment

A standalone window based DSS program v1.1 was developed in Microsoft C# programming language on .NET framework 3.5 by integrating database, key modules, crop-water-salinity-yield module, calibrated AquaCrop and SWAP models to generate and evaluate the BMP based interventions for various resource scenarios in saline environments for enhancing productivity. The developed DSS application consists of six main modules- *Crop Water Demand*, *Canal Supply*, *Groundwater*, *Irrigation Scheduling*, *Modelling*, and *BMPs based Strategies,* and three supporting modules- *Database*, *Farmer's Services* and *Help.* These main modules were validated, debugged and integrated into the main user interface. The *Database module* displays the eight thematic data of the *Irri-agro Informatics Database* for assessing the six saline scenarios/constraints. The *Crop Water Demand* module computes the crop ET from daily weather data for 2001-2013 using Penman-Monteith method and weekly crop coefficient. The irrigation demand at watercourse outlet is thus computed from aggregation of water demand of various crops after subtracting effective rainfall and capillary water, and adding conveyance and application losses. The *Canal Supply* module computes the canal supply and irrigation gap to meet full crop water demand whereas the *Groundwater* module computes the groundwater share with or without water quality consideration. In *Irrigation Scheduling* module, irrigation schedules to maximize/ optimize yield are generated for wheat and other crops from one of four options- canal supply or fresh groundwater in direct or conjunctive mode, deficit irrigation, effective conjunctive mode with poor quality waters, and both water and salinity stresses.

In *Modelling*, a crop-water-salinity-yield response module, and a module with AquaCrop and SWAP were integrated. A crop yield response module for six prevailing saline environments in the WYC command viz, *Surface water stagnation, Waterlogging*, *Soil salinity*, *Soil sodicity*, *Saline/sodic water irrigation*, and *Deficit irrigation* was developed to predict the relative crop yield loss in order to generate and recommend innovative BMPs for minimizing yield loss. This module was validated from the field demo data. The relative yield loss for five major crops (wheat, barley, mustard, pearlmillet and pigeon pea) in *water stagnation and waterlogging* can be predicted for different duration of water stagnation/depth of waterlogging and subsequently, BMPs are recommended for minimizing yield loss. The relative yield loss *in soil salinity and sodicity* can be predicted for rootzone salinity (ECe) and sodicity (ESP) values at sowing, mid and harvest time for five crops. The BMPs for four ranges of ECe (< 4, 4-8, 8-12 and >12 dS m^{-1}) and three ranges of ESP (< 20, 20-50 and >50%) were recommended for minimizing yield loss. The Soil EC converter (EC_2 to EC_e), and soil ESP converter (SAR, pHs and pH_2 to ESP) were developed for use of data from state departments. The gypsum requirement (GR) can be computed using Schoonover's formula or standard GR graph.

Water quality for s*aline/Sodic water irrigation* and its permissible range for direct or conjunctive application in different agro-climatic zones are assessed. The relative yield loss can be predicted for any water salinity/sodicity values for five crops and BMPs with direct/ conjunctive use are suggested for minimizing yield loss. In *deficit irrigation*, the phenological growth stages for five crops are assessed and a deficit irrigation strategy based on number of available irrigations is suggested. A module developed at WTC with yield production functions, AquaCrop and SWAP was integrated under Modelling menu and can estimate the crop yield under varying soil and water salinities, foliar potassium fertilization and salt deposition. SWAP can simulate crop productivity and rootzone salinity build-up wherever site specific input parameters are available. *BMP based strategies* for six saline environments with their quantitative impact, and useful information for farmers on soil and water sampling procedures and testing facilities, salt tolerant and high yielding crop varieties, *Help* and Hindi support are also provided for use of stakeholders.

Wheat Demonstration at Farmers' Fields

In order to develop confidence of farmers on DSS generated BMP based interventions, field demonstrations of wheat crop at 52 farmers' fields in mid and tail reaches of Butana distributary and Jhajjar distributary in saline environments were conducted during three rabi seasons (2010-11, 2011-12 and 2012-13) in Sonipat, Rohtak and Jhajjar districts. The DSS generated BMPs- four high yielding (HD-2967, 2891, and 2894, and DBW-17) and three salt tolerant varieties, (KRL-1-4, 19, and 210), optimum irrigation scheduling, effective conjunctive use of moderate saline, SAR saline and high RSC sodic groundwater, zero tillage, and laser land leveling were evaluated for enhancing crop yield. The wheat yield increased ranging from 17 to 33% in saline environment and improved the income of small farmers by ₹ 13,490-25,700 per hectare. The field demonstrations have infused confidence in stakeholders on DSS generated interventions and these results have also validated the DSS modules.

Transfer of Database, DSS Program and Knowledge to Stakeholders

Since stakeholder's servicing was the important activity of the project with 13% budget allocation, 121 district officers/engineers from CADA, Agriculture and, Irrigation Departments, KVKs and Regional Research Stations (CCS Haryana Agricultural University, Hisar) and NGOs from 12 districts within the WYC Command were imparted skill and knowledge on Database, DSS program and their application through hands-on trainings and workshops for generating BMPs for enhancing productivity in six saline environments. Similarly, 1194 members from canal water users' associations and farmers from Karnal, Panipat, Sonipat, Jind, Rohtak, Jhajjar, Rewari and Bhiwani districts were imparted knowledge on DSS generated BMP based interventions for growing bumper crop yield under six prevailing saline environments.

Upscaling of DSS Program

A feasibility assessment for upscaling of DSS program v1.1 was conducted in 7 KVKs at Panipat, Sonipat, Rohtak, Jhajjar, Rewari, Jind, and Kaithal in terms of availability of computer hardware and software, internet connectivity, manpower, and power supply with generator backup. The problems encountered were non-availability of suitable manpower at Rohtak, and irregular power supply during working hours at Panipat, Sonipat, and Jind due to rural power supply connection. The DSS program was tested at the existing computers at 3 KVKs (Panipat, Rohtak and Rewari) and the backstopping services for deployment are also being provided. Six Divisional offices of CADA at Karnal, Sonipat, Panipat, Rohtak, Jind and Kaithal were also assessed and have met all the requirements for DSS deployment. The upscaling and trainings are being continued from Institute fund and fund from CADA. The stakeholders have shown keenness on use of database and DSS program for solving their field problems.

Part-I: General Information of Sub-project

1. **Title of the sub-project** : Decision Support System for Enhancing Productivity in Irrigated Saline Environment using Remote Sensing, Modelling and GIS
2. **Sub-project code** : 100301
3. **Component** : One
4. **Date of sanction of sub-project** : 19 May 2009
5. **Date of completion** : 31 March 2014
6. **Extension, if granted, from** : 1 April 2012 to 31 March 2014
7. **Total sanctioned amount for the sub-project** : ₹ 355.59740 lakhs (revised)
8. **Total expenditure of the sub-project** : ₹ 217.03576 lakhs
9. **Consortium leader:**

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10. **List of consortium partners:**

Institution	Name of CPI/ CCPI with designation	Name of organization and address, phone, fax & email	Duration (From-To)	Budget (₹ Lakhs)
CL (CSSRI)	Dr. D.S. Bundela CPI & Principal Scientist (SWCE)	Central Soil Salinity Research Institute, Karnal 132001 Phone: 0184-2209418 Fax: 2290480 Email: dbundela@cssri.ernet.in	May 2009-March 2014	196.5844
CP-1 (WTC)	Dr. A. Sarangi CCPI & Principal Scientist (SWCE)	Water Technology Centre, IARI, Pusa, New Delhi 110012 Phone: 09811400885 Email: asarangi@iari.res.in	May 2009-March 2014	107.5966
CP-2 (NIH)	Dr. A.K. Lohani CCPI & Scientist-F (WRDM)	National Institute of Hydrology, Roorkee 247667 Phone: 09412928876 Email: lohani@nih.ernet.in	May 2009-March 2013	51.4164

11. Statement of budget released and utilization partner-wise (₹ in Lakhs):

Institution	CPI/ CCPI	Total budget sanctioned	Fund released (up to closing date)	Fund utilized (up to closing date)
CSSRI	Dr. D.S. Bundela	196.5844	145.75613	130.27850
WTC	Dr. A. Sarangi	107.5966	80.84239	70.81126
NIH	Dr. A.K. Lohani	51.4164	37.44164	15.94600
	Total:	**355.5974**	**264.04016**	**217.03576**

Part-II: Technical Details

1. Introduction

Irrigated agriculture is a major consumer of water resources in which canals contribute to 27% to the total irrigated area at the national level and 42% in Haryana. The massive investment in modernization and rehabilitation of canal irrigation sector in Haryana since Independence has expanded the irrigated area substantially in arid and semi-arid regions with canal irrigation intensity increased to 72% against the designed intensity of 50%. The development of groundwater irrigation for supplemeting deficit canal supplies within the canal commands has further led to intensification of agriculture with the current irrigation intensity reaching up to 186-200% in Haryana from both sources. The effective conjunctive use of canal water with good/ marginal to poor quality groundwater has sustained this intensification in deficit canal supply areas. Therefore, wheat yield has increased substantially from 2.1 in 1970s to 5.17 t ha^{-1} during 2011-12 in Haryana (national average, 3.18 t ha^{-1} during 2011-12). However, the ineffective conjunctive use of such quality waters for irrigation has resulted in low crop productivity as well as waterlogging and soil salinization in many areas of the command which has large variation of wheat yield (15-37%) as head-tail difference.

This large variation in crop yield has continued to bother the government departments, development professionals and research institutions for devising strategies in order to sustain/ enhance the productivity in mid and tail reaches of commands. The large variation in crop yield and productivity is attributed to deficient pattern of monsoonal rainfall, inadequacy and uncertainty of canal water supply, inefficient on-farm water management and ineffective conjunctive use practices with particularly in marginally to moderately saline groundwater zones. The productivity could further degrade due to deferred maintenance of canals, degradation of groundwater quality, diversion of more canal water to other competing user sectors, ongoing secondary soil salinization and waterlogging, and limited capacity of marginal and small farmers' to afford risks. This deterioration in productivity would lead to livelihood problem of millions of marginal and small farmers and further socio-economic conflicts in rural societies living in canal commands.

In order to enhance productivity and to reduce conflicts in farming societies, a holistic approach integrated with advanced geo-information technology and stakeholders' participation needs to be applied to identify and delineate bio-physical resources constraints and their spatial variability in different reaches of the canal command during different cropping seasons for efficient management. Besides, socio-economic information of farmers needs to be integrated to generate best management practices (BMPs) based interventions for canal reach specific problems under various bio-physical and socio-economic constraints for enhancing productivity. Therefore, there is an urgent need to enhance the productivity and income to give a new lease of life to marginal and small farmers through application of DSS (decision support system) generated BMP based interventions. Moreover, there is a need to develop DSS computer program for canal commands for generating realistic BMP interventions in space and time under various resource and socio-economic constraints for enhancing productivity.

With this backdrop, a sub-project '*Decision Support System for Enhancing Productivity in Irrigated Saline Environments Using Remote Sensing, Modelling and GIS*' under Information Communication and Dissemination System sub-component of Component-1 of National Agricultural Innovation

Project was launched on 21 August 2009 to implement in the Western Yamuna Canal (WYC) command of Haryana, Northwest India. The sub-project was aimed to develop resource database and DSS program of the WYC command by integrating bio-physical resources and socio-economic data and modelling within DSS framework for generating and ranking BMP based interventions to enhance productivity in saline environments. The proposed database and DSS program are two deliverable products which would be used by state line departments, KVKs and other stakeholders including progressive farmers for arriving at more plausible and holistic decision scenarios for enhancing productivity under various hydro-climatological uncertainties, resource constraints and socio-economic issues including water limited, salinity limited, waterlogging or combined conditions. Thus, the sub-project was unique in many ways by adopting a consortia mode for project development and implementation, bottom-up approach to problem solving and modelling, state-of-the-art geo-information technology, physically based modelling, and stakeholders' servicing to infuse confidence on the developed DSS application program through demonstrations, workshops and hands-on trainings to address the issues of low crop yield in saline/sodic conditions of the WYC command.

The Western Yamuna Canal System designed as a protective irrigation system (water allowance 2.4-3.01 cusecs per 1000 acres and 50% irrigation intensity) is one of the oldest canal systems in the country having gross and culturable cultivated area of about 13,543 and 10,840 km^2, respectively, was selected for the sub-project on the basis of run-of-the river type barrage scheme, large water demand-supply gap, large area under poor quality groundwater, declining and rising groundwater table zones, severe secondary soil salinization and waterlogging, inadquate drainage infrastructure, arid to semi-arid climate, diverse cropping systems and poor socio-economic conditions of farmers as compared to the other canal commands in the country. The WYC canal system supplies water for irrigation, drinking, domestic, industries and service sectors and takes off from the river Yamuna at Hathnikund barrage constructed across the river Yamuna, 3 km upstream of Tajewala headworks and often suffers from shortage and uncertainty of canal supply during the rabi season despite assured water transfer from Bhakra canal system through NBK link canal. The WYC command is located between 28^0 20' 14" and 30^0 29' 32" N latitude, and 75° 48' 20" and 77° 34' 42" E longitude with elevation ranging from 212.0 to 355.2 m. The command is spread over eastern, central and southern part of the Haryana State covering 5 districts in full (Karnal, Panipat, Sonipat, Rohtak and Jhajjar) and 7 districts in part (Yamunanagar, Kurukshetra, Jind, Hisar, Bhiwani, Rewari and Gurgaon) with 2205 villages (Fig. 1). The command is divided into 8 water service circles (Jagadhri, Karnal, Sonipat, Delhi, Jind, Rohtak, Jhajjar and Bhiwani) for canal administration and management. The command has a state boundary with Uttar Pradesh on the eastern side and National Capital Territory of Delhi on south-eastern side.

The command is facing declining groundwater table problem in Yamunanagar, Kurukshetra, Karnal, Panipat, Sonipat, Jind, Bhiwani and Hisar and rising water table problem in parts in Sonipat, Rohtak, Jhajjar, Jind, Bhiwani and Hisar districts. Due to rising of groundwater table and use of poor quality waters in case of deficit canal water supply, the twin problems of secondary soil salinization and waterlogging are widespread in many areas of Sonipat, Panipat, Jind, Rohtak, Jhajjar and Hisar districts. The twin problems have increased alarmingly in the last decade. The three dominant problems attributed for low productivity in the command are salinity, waterlogging either alone or in combination, and deficit water supply.

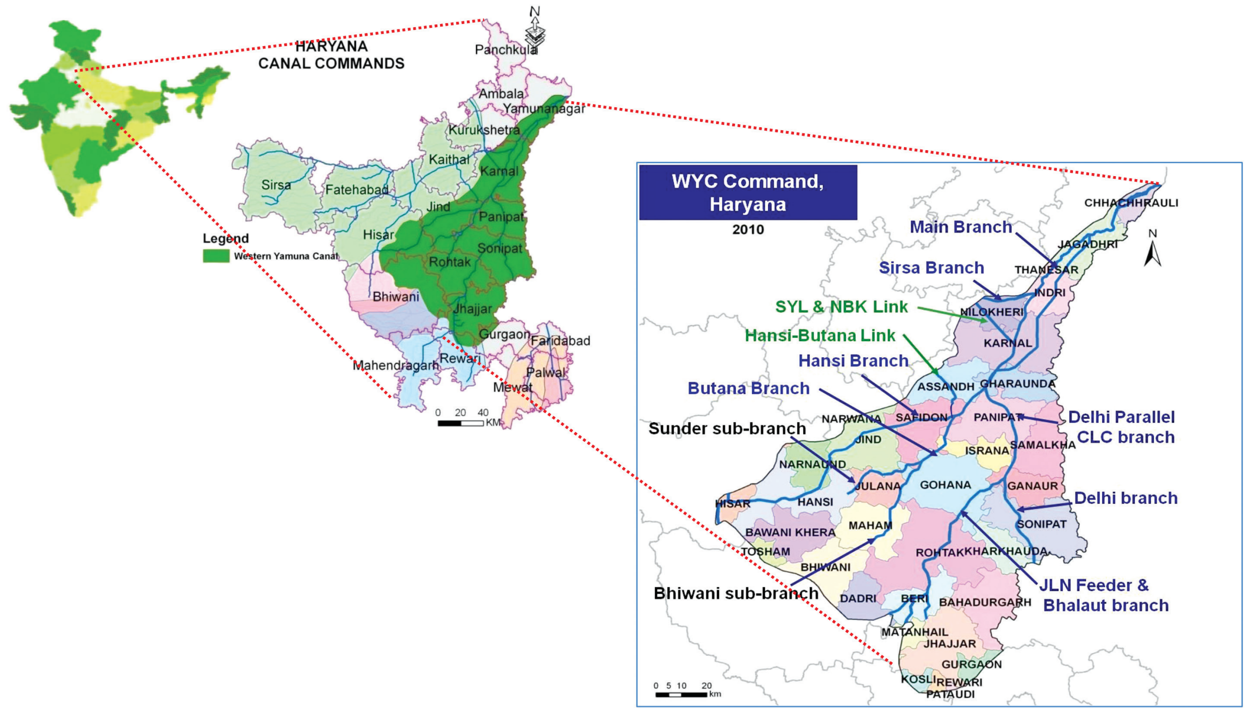


Fig. 1. Location and canal network in Western Yamuna Canal Command

2. Overall Sub-project Objectives

The sub-project was conceived with the overall objective of addressing low crop yield in saline environments and improving rural livelihoods holistically by deploying innovations in Geo-IT, and resource management and crop production technologies to optimize the use of bio-physical resources and by building stakeholders capacity to enhance productivity through convergence of institutions' expertises at watercourse and distributary level. However, the sub-project was undertaken to accomplish the following four specific objectives:

- To characterize bio-physical and socio-economic resources of the WYC command using satellite remote sensing, GPS based field survey, participatory rural appraisal and GIS.
- To predict and upscale crop yield and land and water productivity from field to command scale under various resource constraints and management scenarios using crop-water-salinity-yield production functions and GIS.
- To develop, validate and implement decision support system in the canal command for generating BMP based interventions to enhance the productivity of the command in saline environments, and
- To build-up and enhance stakeholders' capacity on DSS generated scenarios through field demonstrations, customized trainings, workshops and field days for dissemination of knowledge.

3. Sub-project Technical Profile

Objective-wise work plan, monitoring indicators, expected output/deliverable and expected outcome are briefly described as follows:

Objective 1: To characterize bio-physical and socio-economic resources of the WYC canal command using satelite remote sensing, GPS based field survey, participatory rural appraisal and GIS *(Responsible Partners: CSSRI, WTC and NIH).*

Work Plan

- Acquisition and digitization of 12 secondary source thematic maps and data of WYC Command from state departments/central organizations and share with project partners
- Collection and digitization of attribute data for linking to spatial features/layers
- DGPS based primary data collection for gap filling in database
- Conduction of PRA based socio-economic survey
- Acquisition of IRS P6 LISS-3 and 4 imageries of three dates for each *rabi* season and supply to partners
- Collection of ground truth data, image classification for assessment of rabi crops, and estimating *rabi* crop ET from satellite imageries using SEBAL
- Development of a spatio-temporal database on resource and socio-economic information for characterization of the canal command

Monitoring Indicators

- Number of districts and farmers identified for baseline information
- Number of questionnaires distributed/filled in during PRA survey
- Number of GIS thematic layers and attribute data digitized in spatial database

Expected Deliverable

- *Irri-agro informatics* spatial database of the WYC command

Expected Outcome

- Information on characterization of the canal command in terms of canal supply status, groundwater quality, soil salinity, rainfall distribution and soil texture for identifying resource constraints for predicting crop yield
- Database distribution and online sharing with stakeholders

Objective 2: To predict and upscale crop yield and land and water productivity from field to command scale under various resource constraints and management scenarios using crop-water salinity production functions and GIS *(Responsible Partners: CSSRI and WTC).*

Work Plan

- Stratification and delineation of low productivity area in the command using GIS
- Assessment of canal supply-demand during *rabi* season
- Establishing crop-water-salinity-yield relationship and vegetation indices for assessing crop growth and predicting yield of major crops in air, water and salt stress

- Estimation of canal supplies at different reaches in canal segments during *rabi* season
- Estimating variations of groundwater availability and quality in the canal command
- Identification of different resource constraints and management scenarios for addressing low productivity
- Identification of BMPs for enhancing productivity and devising adaptation measures including extreme storm events
- Demonstration of BMPs at farmers' fields
- Prediction of productivity under different management scenarios using production functions and its upscaling to command scale using GIS

Monitoring Indicators

- Number of crop production functions tested/generated using crop yield data under various resource constraints and management options
- Number of demonstrations of BMPs at farmers fields
- No of BMPs identified for saline conditions

Expected Deliverable

- Area of low productivity district/village wise in the command
- List of BMPs in six saline conditions and adaptation measures for enhancing productivity
- Upscaled map of wheat yield in the WYC command

Expected Outcome

- Increased awareness of suitable BMPs in six saline conditions for increasing crop yield
- Increased adoption of BMP based interventions by farmers for improving crop yield

Objective 3: To develop, validate and implement decision support system in the canal command for generating best management practices based interventions to enhance the productivity of the command in saline environment. *(Responsible Partners: CSSRI, WTC and NIH)*

Work Plan

- Development of a modular architectural framework of DSS in view of data availability
- Development of DSS for linking with existing and created spatial databases, and models, spatial query generator, output retrieval and graphic display
- Testing, validating and fine-tuning of DSS under different resource and management scenario for generating BMPs to enhance productivity in the selected canal command
- Demonstration of developed DSS and its capability to stakeholders for decision making

Monitoring Indicators

- Release of first and other versions of DSS program
- Number of problems and their solutions in testing and fine-tuning of DSS
- Release of customized versions of DSS program
- No of hands-on trainings conducted

Expected Deliverables

- DSS program of the WYC command for generating BMPs based interventions for enhancing productivity
- Customized DSS versions for various stakeholders

Expected Outcome

- Enhanced knowledge of stakeholders on use of DSS application for improving crop yield and livelihood

Objective 4: To build and enhance stakeholders' capacity on DSS generated scenarios through field demonstrations, customized trainings, workshops and field days for dissemination of knowledge *(Responsible Partners: CSSRI and WTC).*

Work plan

- Sensitization and capacity building of state line departments and KVKs to the problems in water management in saline conditions and use of DSS program for problem solving
- Sensitization and capacity building of canal water users' associations and progressive farmers to the problems in irrigated agriculture and DSS generated BMP interventions
- Demonstration of DSS generated BMPs at farmers' fields for enhancing productivity
- Economic impact analysis of beneficiaries under adoption of BMPs
- Conduction of an interaction workshop for state line departments, WUAs and farmers

Monitoring Indicators

- Number of trainings (man-days) on sensitization and capacity building of CADA, Irrigation and Agriculture Departments, Canal Water User Associations, HLRDC, KVKs and progressive farmers
- No of field demonstrations based on DSS generated BMPs
- Expected Deliverables:
- Enhanced capacity and skills of stakeholders on operating DSS for generated BMPs
- 30 officers of CADA, irrigation and agriculture departments
- 500 members from 400 water users' associations of the WYC command and 500 farmers from the WYC command
- 50 No of field demonstrations of DSS generated BMPs

Expected Outcome

- Enhanced capacity and skills of stakeholders for use of DSS program and DSS generated BMP based interventions

4. Baseline Analysis

Two study branch canal commands under WYC Command- Butana Branch in Sonipat and Rohtak districts, and Bhalaut Sub-branch in Rohtak and Jhajjar districts were selected for collecting baseline information and for assessing crop production constraints and coping up strategies adopted in mid and tail reaches of both canal commands in saline environment. Historical satellite imageries, secondary source data, field surveys, transect walk, canal conditions and supply assessment, and participatory rural appraisal (PRA) were used in the beginning of the project (2009-10) to assess the bio-physical resources constraints and socio-economic conditions of farmers. Seventy and one hundred farmers were selected as sample size for PRA from the Butana branch and Bhalaut sub-branch canal commands (Sonipat, Rohtak and Jhajjar districts), respectively. A total of 170 farmers selected through random sampling were interacted through a questionnaire and their perception on water management and control of waterlogging and salinity. The loss of crop productivity and low farm income due to twin problems were reported by the farmers. About 85 to 100% of the respondents strongly endorsed that the deferred/poor maintenance of irrigation channels leading to seepage and leakage from distributaries and minors, low supply of canal water and canal siltation and weed growth were the major issues which led to waterlogging and subsequent soil salinization in the commands. About 85% of the respondents opined about non-existence of any scheme by the government agencies for maintenance and rehabilitation of watercourses (field channels).

It was found from the analysis of resources constraints that deficit canal supply in marginal to poor quality groundwater areas, growing of high yielding *rabi* (wheat) crop varieties in waterlogging and soil salinity conditions, ineffective conjunctive use of marginal and poor quality saline and sodic groundwater with canal water, inadequate use of gypsum for sodic groundwater and soils, poor irrigation scheduling, lack of precision land leveling, and broadcasting sowing method were the main constraints that have resulted in average low wheat yield (1.9-2.5 t ha^{-1}) as well as moderate to high soil salinity built up (8-20 dS m^{-1} ECe) in croplands at harvest in both commands. Seventeen per cent more area under soil salinity and waterlogging was reported in Butana canal command in comparison to Bhalaut sub-branch command. About 62-70% of marginal and small farmers were located at tail ends in the Butana and Bhalaut branch commands and the low level use and spread of suitable technologies for saline environment were also observed in both the commands. As coping-up strategies, farmers managed the twin problems by cleaning of watercourses, digging field drains, controlled irrigation with effective conjunctive use, precision land leveling, use of gypsum, and increasing seed rate and fertilizers besides green manuring with varying degrees of successes. Nonetheless, it was revealed from this study that farmers' desired active knowledge dissemination mechanism with technology details, funding opportunities and functioning of canal water user associations/societies besides involvement of all farmers for enhancing productivity from irrigated saline environment in the WYC command.

The socio-economic characteristics of farmers acquired from baseline surveys were analysed and it was observed that 48% of the respondents were in the age group ranging from 35 to 53 years followed by 37 and 30% in young (18 to 34 years) and old age (above 53 years) category, respectively (Table 1). Educational status of the farmers revealed the maximum percentage (42%) of the respondents had high school education while 30% respondents were educated up to intermediate level. It was observed that only 5 percent of the respondents were educated up to graduation. However, 18% of the respondents were illiterate and have not done any primary schooling. In general, the educational status of the farmers was observed to be of moderate nature. Most of the respondents (57%) belonged to nuclear family category followed by joint family category (43%). Majority of the respondents (88%) had agriculture as their main occupation. Moreover, 10% respondents were engaged in animal husbandry/dairy business besides agriculture. The other occupation as their primary occupation was reported by only 2% respondents. Regarding land holding size, 38% farmers belonged to large farmers category (>10 ha) followed by 33 and 29% belonging to small (1-2 ha) and marginal (<1 ha) farmer categories, respectively. The annual income of the respondent was categorized on the basis of the Government of India Economic Census (2000). The income from various sources was accounted in the study. Majority of the respondents (53%) had middle category of annual income followed by high (30%) and low (17%) category of annual income. Majority of the respondents (90.5%) were not having any membership in any social organization followed by membership in one organization (5%) and more than one organization (2.5%). Most of the respondents (69%) belonged to high level of agricultural mechanization followed by medium (18%) and low (13%) degree of agricultural mechanization.

Table 1. Profile of farmers in the study area (N=170)

S. No.	Socio-economic characteristics	Majority/major characteristic	Percentage
1.	Age	Middle age group (35–53 years)	48
2.	Education	Up to high school	42
3.	Family type	Nuclear type	57
4.	Occupation	Agriculture	88
5.	Land holdings	Large farmers	38
6.	Income	Medium category	35
7.	Social participation	No membership	92
8.	Degree of agricultural mechanization	High level	69

Farmers in the command recognized various irrigation and drainage related problems responsible for waterlogging and soil salinization processes. The perceptions of farmers on such irrigation and drainage problems were examined and all the farmers (100%) agreed that surface drainage system existed in their areas. About 90% respondents contended that surface drainage system was not working to its full capacity due to heavy siltation and weed infestation (Table 3). It proved to be grossly inefficient to carry excess drain water to the main drainage system laid down in the command. According to 85% farmers, there was no any provision of monitoring and maintenance of the drains by the government. Farmers (88%) also showed apprehensions about the role of canals in aggravating the conditions for waterlogging and soil salinization. Poor maintenance of distributary and minor canals or field channels and no strict roster of canal supply of water in the canal system were also considered important factors contributing to waterlogging and soil salinization by 85% and 87% of the respondent farmers, respectively. Other notable perceptions held by the farmers were the adverse impact of the existence of canal system at nearby areas of village and use of canal water for non-irrigation (commercial) purposes. These views were shared by 65 and 75% respondents, respectively. Some farmers believed that flood irrigation method is the best for water management practice and *Kharif* season is most affected season due to waterlogging. However, farmers were neutral to the opinion that government facilitates to remove the extra water from fields were poor and easy and timely access of water supply from the canals were contributing causes for the problem. The majority of the farmers recognized that waterlogging problem was noticed with the advent of canal irrigation systems in these districts and this was followed by salinity problem. On the spread of waterlogging and soil salinity problems, 60% felt that, waterlogging was less severe during the *Kharif* season and problem of salinity was more severely felt in *Rabi* and s*ummer* seasons.

Table 2. Irrigation and drainage conditions promoting waterlogging and soil salinity

S. No.	Indicator	Rank	Percentage
1	Existence of surface drainage system in village areas	SA	100
2	Man-made and natural drains are silted and chocked-up with weed infestation and debris	SA	90
3	No provision of monitoring and maintenance of drains by the government	SA	85
4	Adjacent areas to canals are mostly affected by waterlogging due to seepage losses and leakage from canals	SA	88
5	Poor maintenance of distributary or minor canal systems	SA	85
6	No government regulation to monitor the supply of canal water	A	87
7	Poor governmental facilitates to remove the extra water from field (when required)	N	54
8	Existence of canal system for irrigation purpose at nearby areas of village	A	65
9	Easily and timely access of water supply from minors	N	56
10	Canal water used of commercial purposes as well	A	75
12	Flood irrigation method is best for water management practice	A	65
13	*Kharif* season is mostly affected due to waterlogging	SA	60

Notations used: N: Neutral, A: Agreed and SA: Strongly agreed

Coping up strategies adopted by farmers' of the study area

Various coping up strategies were adopted by the farmers to combat the waterlogging and soil salinity problems (Table 3). These measures were classified under mechanical, irrigation and cultivation practices. Among mechanical measures, cleaning of field irrigation channels and creation of open field drains were resorted to by 85 and 67% of the respondent farmers, respectively. Controlled irrigation was also practiced by majority of the farmers (85%). However, under cultivation practices measures increase in seed rate and nitrogenous fertilizers were the most common strategies adopted by most of the farmers (96%) to mitigate the adverse impact of the soil salinization, both in waterlogged and saline areas. Deep and frequent ploughings were adopted by 94% farmers. Growing green manure crops, increased use of organic manure, land leveling and watercourse deepening and embankment strengthening were some of the other measures practised by the respondent farmers in the study area.

Outcome of focused group discussion

Different dimensions of each of the issues under study were closely observed and discussed with farmers. Some of the major observations are as follows:

- Farmers of the selected villages followed the five cropping systems, paddy-wheat, cotton-wheat, bajra-wheat/mustard, sorghum-wheat, and sugarcane-wheat. Some farmers didn't raise any crop due to lack of canal water availability during summer season. Farmers used to take green manuring crop for maintaining or upgrading soil fertility status.
- Farmers used to take crops related information from input suppliers, progressive farmers from village, neighbours and friends, etc.

- The farmers facing problems of waterlogging and consequent soil salinization undertook preventive and coping up measures to get rid of twin problems. But many farmers expressed that the extent of problem and lack of resources were the main reasons for their inability for not adopting any measure. Lack of incentives and technical know-how were the other reasons expressed by the farmers. The farmers also felt the need for community approaches to combat the soil salinization problems as individual actions were not sufficient to reclaim the saline lands. Some farmers brought the extent of soil salinity problems and their severity to the notice of *Panchayat*, the village level local body but without any fruitful response.

Table 3. Coping-up measures/strategies followed by farmers (N=170)

S. No.	Measure/strategy	Number of farmers		
		Waterlogged (N_1=95)	Salinity (N_2=75)	Total (N =170)
1	Cleaning of field irrigation channels frequently	95 (100)	65 (87)	160 (94)
2	Created open field drains to get rid of extra water	74 (78)	56 (75)	130 (76)
3	Controlled irrigation methods used	71 (75)	70 (93)	141 (83)
4	Grow green manure crop to upgrade soil fertility and physical status	50 (53)	68 (91)	118 (69)
5	Increase in seed rate	91 (96)	75 (100)	166 (98)
6	Increase use of organic manure	45 (47)	48 (64)	93 (55)
7	Increase use of nitrogenous fertilizers	65 (68)	70 (93)	135 (79)
8	Soil amendment application and plant management for reducing salinity and waterlogging	28 (29)	45 (60)	75 (43)
9	Deep and frequent ploughing	91 (96)	64 (85)	155 (91)
10	Land leveling and bunding	44 (46)	43 (66)	87 (57)

Note: Figures in parentheses indicate percentage of the total

5. Research Achievements

The sub-project adopted a flexible research approach to accommodate site specific interventions and needs of stakeholders for achieving its four objectives. This has provided much needed freedom to address issues related to development and online dissemination of bio-physical and socio-economic resource database, development and deployment of DSS program, stakeholders servicing, transfer of DSS knowledge, available computer system, and crop yield and livelihood improvement in saline environments. However, the achievements made in the sub-project were broadly classified into eight major themes: *Irri-agro* Informatics Spatial Database, AquaCrop and SWAP models for predicting wheat yield and rootzone salt dynamics, Crop water demand driven canal schedule, DSS program for enhancing productivity, Field demonstrations, Wheat yield at command scale, Transfer of Database and DSS knowledge to stakeholders, and Upscaling of DSS program. The detailed account of research achievements objective-wise made under the major themes are presented as follows:

Objective 1

- **Development and Online Dissemination of *Irri-agro Informatics* Spatial Database of the WYC Command for Resources Characterization**

Since a spatial database of the WYC command on bio-physical and socio-economic resources was the first requirement of the sub-project for characterizing and locating its resource constraints for sustaining high productivity, an *Irri-agro Informatics* Geodatabase of the Western Yamuna Canal command (Fig. 2) was developed using GIS tools from the secondary source maps and data, satellite remote sensing data, and GPS field surveys, and is comprised of 14 layers viz. canal network, canal system characteristics and inflow data, groundwater quality, salt-affected soils, rainfall pattern, soil texture, cropping system, terrain, waterlogging, geology, land use, rail and road infrastructure, socio-economic data, canal water users' association data, satellite data derived current land use, and digital cadastral data. Fourteen secondary source maps and data acquired from ten central or state organizations/ departments (Table 4) were digitized in ArcGIS v10 for developing the geodatabase. The geodatabase was updated periodically with the current season crop, inflow and remote sensing data and information extracted from remote sensing imageries on new link canals, distributaries, minor and watercourses, and extension of existing canals and roads. Land use maps of the Butana distributary command, Jhajjar distributary command and WYC Command for the 2012-13 rabi season was generated from Resourcesat-1 LISS-3 and 4 data, respectively, using digital image interpretation and analysis techniques of ERDAS Imagine v10. The information on ten key themetic layers are presented as follows:

Rainfall

The WYC command has arid to semi-arid climate with hot weather prevailing in the command between March and October. Most monsoonal rainfall occuring from July to September leaches down the neutral salts from the root zone to deeper layers and helps in desalinization of salt-affected soils. Winter rainfall occurs from December to February, supplements irrigation requirement of the rabi crops. The distribution of annual rainfall in the command was classified into six classes. The annual average rainfall over the command is 580 mm and varies from 900 mm in Yamunanagar district to less than 400 mm in Bhiwani district. Rainfall during the *rabi* season ranges from 100 mm in Yamunanagar district to less than 50 mm in Bhiwani district. Moreover, 70% area of the command falls between 400 and 600 mm. Irrigation requirements also vary from north east to southwest. Annual reference evapo transpiration over the command ranges from 1100 mm at Yamunanagar (head) to 1625 mm at Karnal (mid) and 3320 mm at Hisar/Bhiwani (tail). The departure of monsoon rainfall from 2006 to 2013 against the long term average was also included in the database.

Table 4. Maps and data from secondary sources used for the *Irri-Agro Informatics* geodatabase

Data	Scale	Data product	Year of pub.	Source
OSM series topo maps	1:50,000	Digital Vector	1997	Survey of India
Canal network	1:50,000	Map	1996	Irrigation Dept, Haryana
Soil salinity	1:500,000	do	1996	CSSRI/ NBSSLUP
Shallow GW quality	1:500,000	do	2006	CGWB
Deep ,, ,,	1:500,000	do	2001	HSMITC/Agri Dept
Waterlogging	1:500,000	do	2005	CSSRI/ NRSC
Land use	1:250,000	do	2005	Agriculture Dept/NRSC
Soils	1:500,000	do	1996	NBSSLUP
Roads	1:250,000	do	2010	B&R, PWD
Rainfall	1:500,000	do	2005	IMD/CSSRI
Socio-economic	Village	Digital	2001	Census Haryana
Canal discharge	Point	Sheet	2011	Irrigation Department
Water table data	Point	Digital	2010	Agriculture Department
Canal WUAs	Point	Sheet	2010	CADA/ Irrigation Dept

Canal network

The Western Yamuna canal system takes off from the river Yamuna at Hathnikund barrage. The Hansi Branch takes off from main canal at Munak and Butana Branch from Hansi Branch at Anta. The Hansi Branch and Butana Branch supply water to the three selected distributaries- Gangesar, Butana and Kahanaur. The Bhalaut Sub-branch takes off from Delhi Parallel Branch at Khubru and its Jhajjar sub-branch supplies water to the Jhajjar distributary. The entire canal network was classified into three levels-main canal (primary), distributary canal (secondary) and watercourse (tertiary). The total length of the WYC network with all its branches is 325 km. In addition, about 32 distributaries and 95 minors make up its combined length of 1220 km. Further to prevent seepage losses along the WYC and to augment its supply, a lined Augmentation Canal over 69 km was constructed in 2000. It takes off from Yamuna Nagar and out falls in WYC upstream of the Munak head. The WYC system receives a fixed amount of water (average 1800 cusecs) from the Bhakra Canal system through Narwana branch-Karnal (NBK) link canal which augments the supplies in the WYC on Main Branch near Munak Head.

Rabi season canal rotations and supplies

The available supplies in the WYC system are far short of the total crop water requirement of the entire culturable command area (CCA). Therefore, available supplies are delivered in turn by formation of four rotation groups viz. JLN group, Butana group, Sunder group, and Bhalaut group. The Gangesar and Butana distributaries run under Sunder group and Kahanaur distributary under Butana group and Jhajjar distributary under Bhalaut group. During three *rabi* seasons 2010-11, 2011-12 and 2012-13, the Western Yamuna canal system was operated from mid October to mid April following a set pattern of four group rotations (Annexure-I, Table A.1 & A.2). As a result of the allocation schedule and the fixed water allowance, the command area serviced by the Butana branch and Bhalaut sub-branch channels received the largest quantity of water per unit area because water was supplied on 8 days on and 24 days OFF periods during the *rabi* season. Canal share for irrigation in the WYC system during *rabi* season 2012-13 was 73.8-75.2% and canal share for non-irrigation was 24.8-26.8% used for drinking, domestic, industries and other service sectors Drinking water share for small villages could not be accounted in this share. Three canal supplies were given to the crops during *rabi* season 2011-12 and 2012-13 and remaining irrigation demand was met from available good/ poor quality groundwater.

Groundwater

In addition to canal water, groundwater supplements a major irrigation requirement of crops in the WYC command. Deep tube wells in north and central areas and shallow tubewells in centre and south west areas irrigate an area equal to or greater than the area irrigated by canal water. The command area is underlain by good quality groundwater, marginal quality, saline-sodic and saline groundwater and in the last two decades, the water table has risen substantially (<3 m) in a large portion of Rohtak and Jhajjar districts. The continued rise in water tables in other areas is one of the major problems in the command.

Salt-affected soils and soil texture

As a result of canal irrigation, many part of the WYC command experienced a significant increase in crop yield. However, irrigation has also brought problems such as waterlogging and soil salinity, which not only degraded the good irrigated agriculture but also devastated the villages. The salt-affected soils were classified into two classes- sodic and saline for the reclamation. The entire command was classified into four soil textural classes - sand, loamy sand, sandy loam, and loam.

Cropping systems

Five major cropping systems are prevalent in the WYC command. Rice-wheat is a major cropping system dominant in Kurukshetra, Karnal and Yamunanagar districts in full, and Jind, Sonipat, Panipat, Rohtak, Jhajjar, and Hisar districts in parts. Bajra-wheat/mustard is followed in parts of Rohtak, Bhiwani and Hisar districts. Sorghum-wheat, and cotton-wheat is followed in parts of Rohtak, Bhiwani and Hisar districts. There are few other cropping systems exists in the WYC command.

Village, tehsil and district information

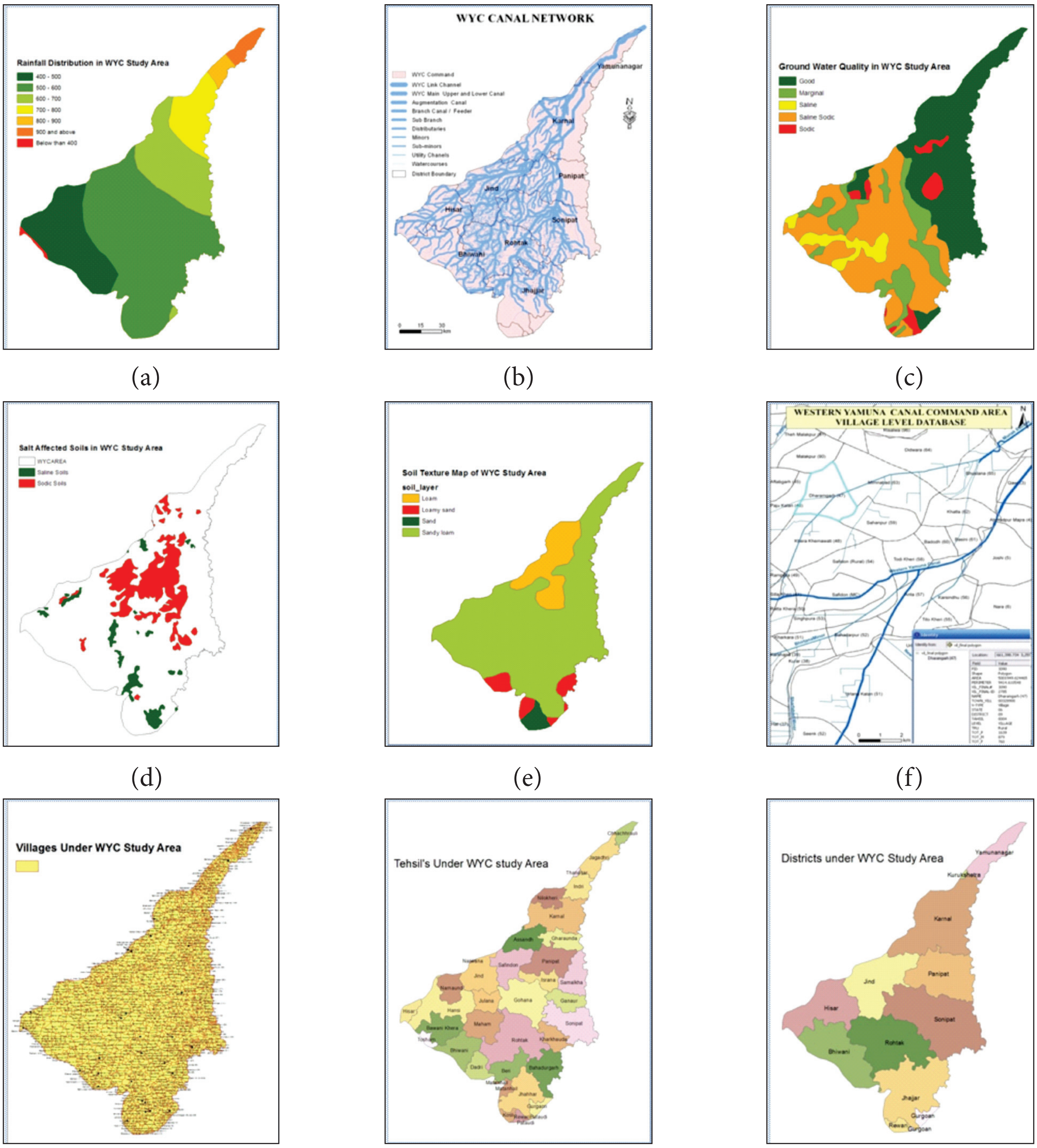
Village, tehsil and district information provide detailed information on demographic, social, infrastructure and land use of each village, tehsil and district from 2001 census in the form of maps, tables and figures. The village layer contains information on village, total households, total population, total male population, total female population, SC population, SC male population, SC female population, village area, total irrigated, unirrigated area cultivable wasteland, and non-cutivable wasteland.

Characterization of bio-physical and socio-economic resources at different levels

Entire Command (WYC)

The updated geodatabase has characterized the bio-physical resources at entire command, district, tehsil, distributary, village, watercourse and farm levels. The bio-physical resource characteristics of the WYC command are of 3 levels in canal network- primary, secondary and tertiary canals with system and inflow characteristics; 4 rainfall departure classes (excess, normal, deficient and scanty) during 2006-13; 6 rainfall zones - 18.6% area (<500 mm), 51.6% (500-600 mm), 17.3% (600-700 mm), 8.8% (700-800 mm), 1.6% (800-900 mm), 2.1% (>900 mm); 5 groundwater (GW) quality classes- good (38.3% area), marginal (15.2%), saline (5.3%), sodic (4.2%) and saline-sodic (37%); 2 salt-affected soils (SAS)- saline (4.0%), and sodic (14.5%); 4 soil texture classes- sand (2.4%), loamy sand (6%), sandy loam (78.6%), and loam (13%); and 5 cropping systems (rice-wheat, bajra-wheat/ mustard, sorghum-wheat, cotton-wheat, and sugarcane-wheat (Fig. 2a-2i).

District level



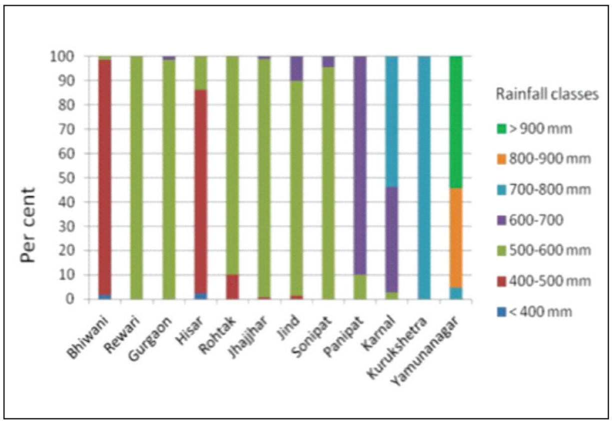
(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Fig. 2. Nine thematic layers of *Irri-agro Informatics Geodatabase* of the WYC Command- rainfall distribution (a), canal network up to watercourses (b), groundwater quality (c), salt-affected soils (d), soil textures (e), village socio-economic data (f), villages (g), tehsil (h) and district (i)

The geodatabase has also characterized the resources of 12 districts of the WYC command based on rainfall distribution, groundwater quality, soil quality and soil texture. The rainfall distribution varies from 900 mm in Yamunanagar district to less than 400 mm in Bhiwani district (Fig. 3a). Bhiwani district has the largest area under saline-sodic groundwater whereas Yamunanagar and Kurukshetra districts have almost good quality water (Fig. 3b). Similarly, Yamunanagar and Kurukshetra, and Bhiwani and Rewari districts have normal soil where as eight other districts have some level of sodic and saline soils (Fig. 3c).



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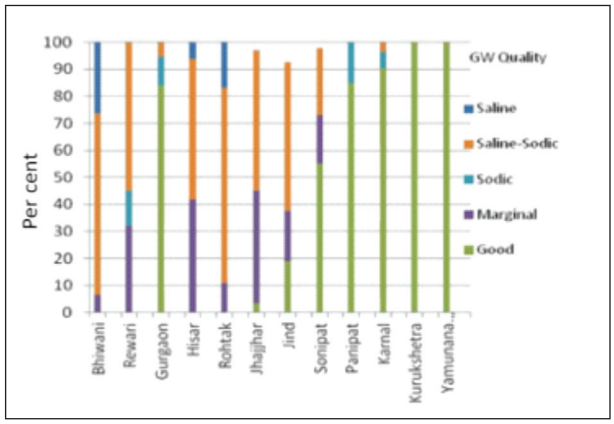

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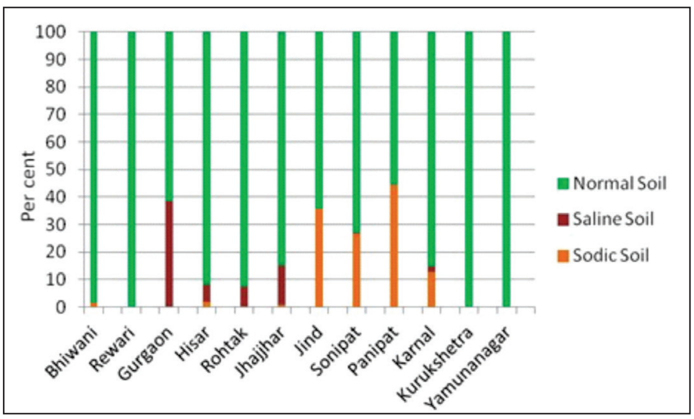


(c)

Fig. 3. District-wise distribution of rainfall distribution (a), groundwater quality (b) and salt-affected soil classes (c) in the WYC command

Tehsil level

The database has characterized Gohana tehsil (Sonipat district) into four groundwater quality classes and two salt-affected soil classes (Fig. 4). The Gohana tehsil contains good quality groundwater (16% area), marginal (42%) and poor quality water (42%) whereas sodic soil is in 0.6% area and saline soil in 46% and the remaining area as normal soil (Table 5). The Butana distributary command covers almost 93% under Gohana tehsil and the remaining area in Rohtak tehsil under Rohtak district. The database can identify and locate the resource constraints for planning the crop production strategies to optimise crop yield in different resource scenarios.

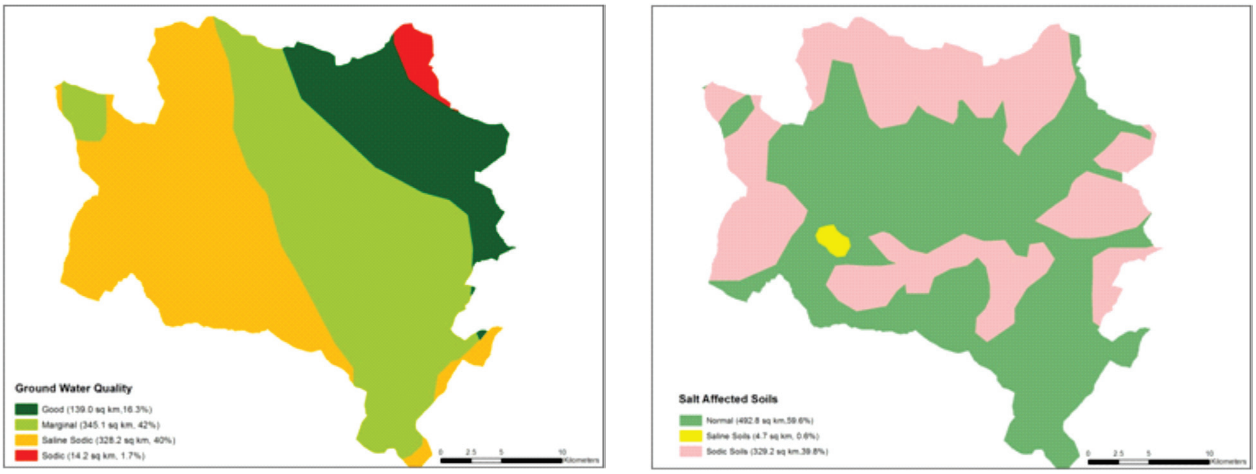


Fig. 4. Spatial distribution of groundwater quality, and salt-affected soils in Gohana tehsil

Table 5. Area under different groundwater quality and salt-affected soil classes in Gohana tehsil

Thematic layer	Class	Area (km²)	% area
Groundwater quality	Good	139.0	16.3
	Marginal	345.1	42.0
	Sodic	14.2	1.7
	Saline-sodic	328.2	40.0
Salt-affected soils	Saline	4.7	0.6
	Sodic	329.2	39.8

Distributary level

Butana distributary command has an area of 145.92 km² and high density of canal network with 31.36 km length in which 28.38 km canal length spreads in Sonipat district and 2.99 km in Rohtak district (Fig. 5). Its water allowance at outlet is 3.01 cusecs per 1000 acres and the channel capacity is 227.3 cusecs. The distributary has three minors- Gudha, Baroda and Ahulana, and four sub-minors- Baroda, Khandrai, Kathura and Katwara. The Butana distributary and its minor and sub-minor canals are lined channels whereas the 62% of watercourses are lined and the remaining are earthen channels. The climate of the Butana distributary command is semi-arid which is characterized by hot-dry and windy summers, cold winters and humid-warm monsoon months. Butana distributary has 70% canal irrigation intensity and 186% overall irrigation intensity with conjunctive use of groundwater. The groundwater is extensively used to supplement the crop irrigation demand, if not met by canal water. The around 66% of the command is irrigated by canal network and 34% by tubewells (Fig. 6a). The command receives a uniform and average annual rainfall in range of 500-600 mm (average actual rainfall 500-543 mm during 2005-2013) (Fig. 6b). In addition to scanty rainfall, the erratic occurrence of rainfall aggravates the problem to soil salinization to a great extent.

The groundwater quality plays a significant role in enhancing productivity and also contributes soil salinization in areas of marginal to poor quality groundwater. The marginal quality groundwater of saline and sodic nature was present in 44.7% in the head and mid reaches (northeast part), whereas saline-sodic groundwater occupied an area of 55.3% in mid and tail reaches (south west part) of the Butana

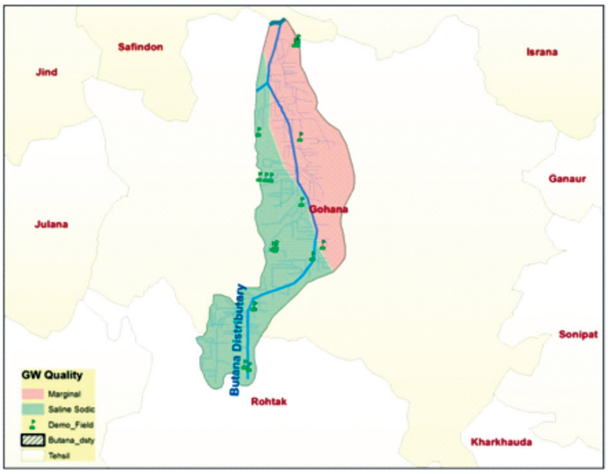


Fig. 5. Spatial coverage of Butana distributary command in Gohana tehsil (Sonipat district)

distributary command (Fig. 6c). On an average, good quality water is not available in the command except in small patches adjoining canal network, village ponds, and drains. The irrigation of such quality groundwater to crop in mid and tail reaches of the command leads to soil salinization and sodication and resulting in low crop yield, if sound management strategies were not followed. The soil-texture is sandy loam which covers the entire distributary command. Being a coarse texture, the soils are poor in water and nutrient retention and low in organic carbon and phosphorus.

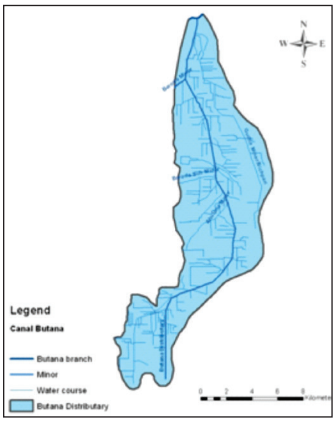
The salt-affected soils are prevalent in the distributary command and the area under sodic soil was found to be 34.3% area and the normal soil covers the remaining 65.7% area (Fig. 6d). Most of sodic soils are under cultivation except large patch under community lands and this is mainly due to good supply of canal water and adoption of sodic reclamation technology. Even before introduction of canal irrigation, the Butana distributary command was affected majority by saline-sodic soil. On partition of saline-sodic soil into saline and sodic soil for reclamation, majority of soils falls in sodic class category. Since coarse soil texture was favourable to apply marginal and low salinity water for irrigation, wheat crop was grown.

Twenty seven villages lie in the Butana distributary command and the main villages in head, mid and tail reaches are Jagsi, Gangana, Bichpari, and Butana; Gangesar, Khandrai, Gudha, Baroda, Khanpur Khurd, Ahulana, Thaska, Madina, Kathura, and Bhaiswan; and Chhichhrana, Mirzapur Kheri, Sanghi, and Khaswali, respectively (Fig. 6e). Twelve villages were partly covered within the command. The command has dense network of roads to access the villages and minor and sub-minor canals (Fig. 6f). A single metalled road runs through from the head reach at Jagsi to the tail reach at Sanghi in the command to access the command for field survey and sampling works.

Village level

Three villages in the Butana distributary command (one each at head, mid and tail reaches) were selected for assessing the groundwater quality and salt-affected soils (Fig. 7). Groundwater quality deteriorates from the head to tail reaches in Butana distributary command whereas soil quality improves from head to tail reaches. Gangana village (head reach) has 65.6% area in marginal and 34.4% area in saline-sodic groundwater quality (Fig. 8) whereas Ahulana village (mid) has 11% in marginal and 89% in saline-sodic water classes (Fig. 9). At the tail end (Sanghi), groundwater quality is of 100% saline-sodic (Fig. 10) which can be reclaimed with gypsum application. Soil quality is in

97.5% area as sodic soil at head reach and 0% at tail reach (Table 6). The village layer also contains socio-ecnomic information including village name, total households and total population, total male and female population, SC population, SC male and female population, village area, total irrigated, unirrigated area, and cultivable and non-cultivable wasteland (Table 7) which could be utilized for generating BMPs for faster adoption.



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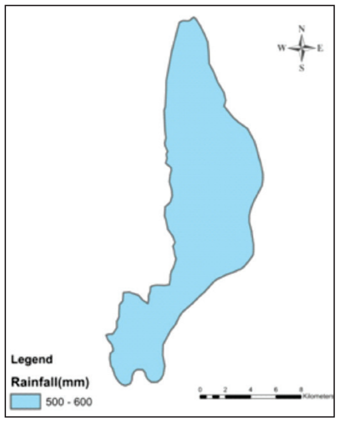

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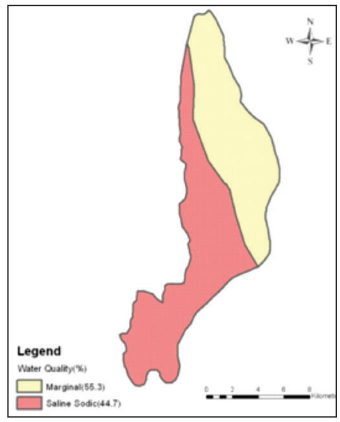

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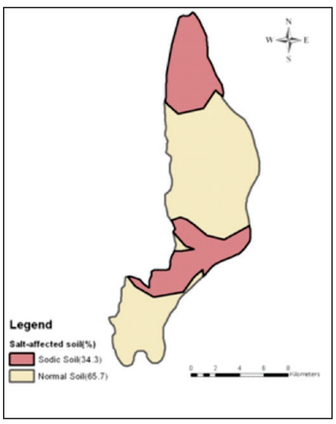

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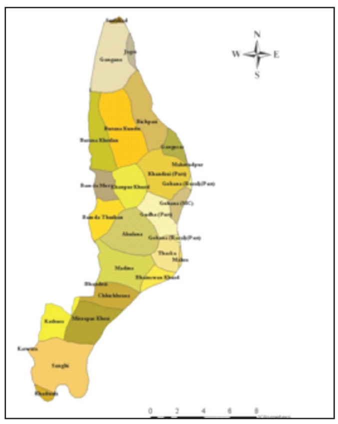

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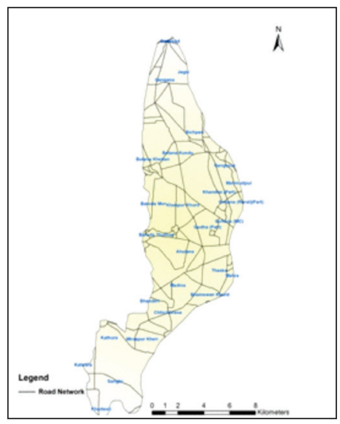


(f)

Fig. 6. Thematic layers of Butana distributary command- Canal network (a), Rainfall distribution (b), Groundwater quality (c), Salt-affected soils (d), Villages (e) and Road network (f)

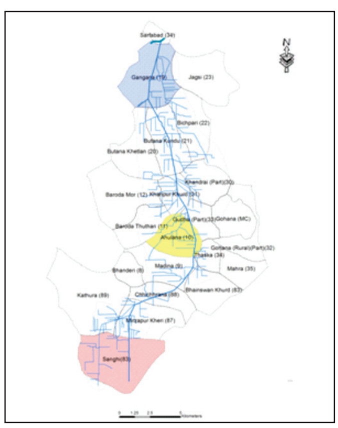


Fig. 7. Location of three selected villages in Butana distributary command

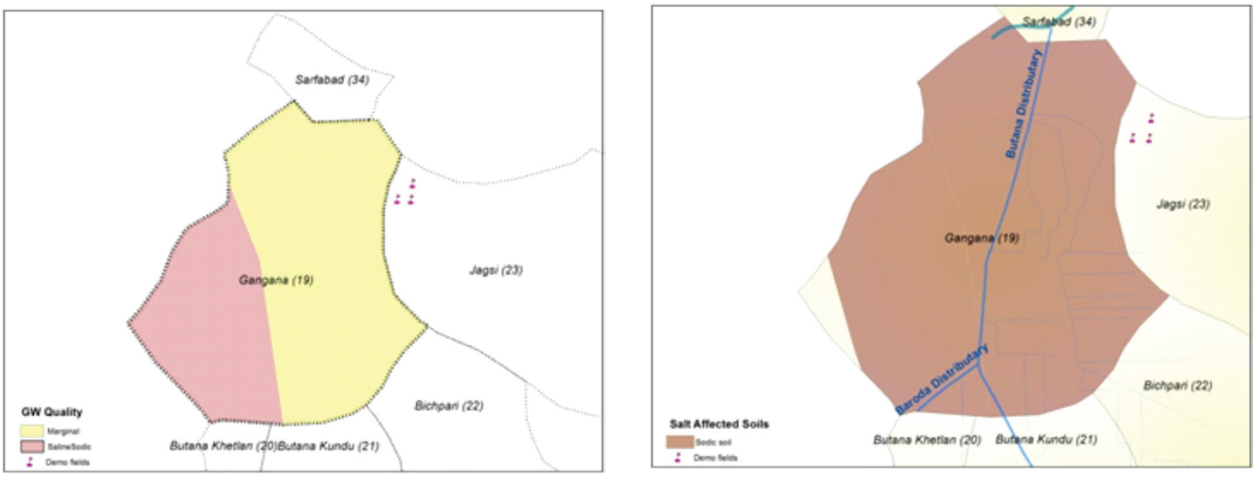


Fig. 8. Groundwater quality and salt-affected soils in Gangana village (head reach)

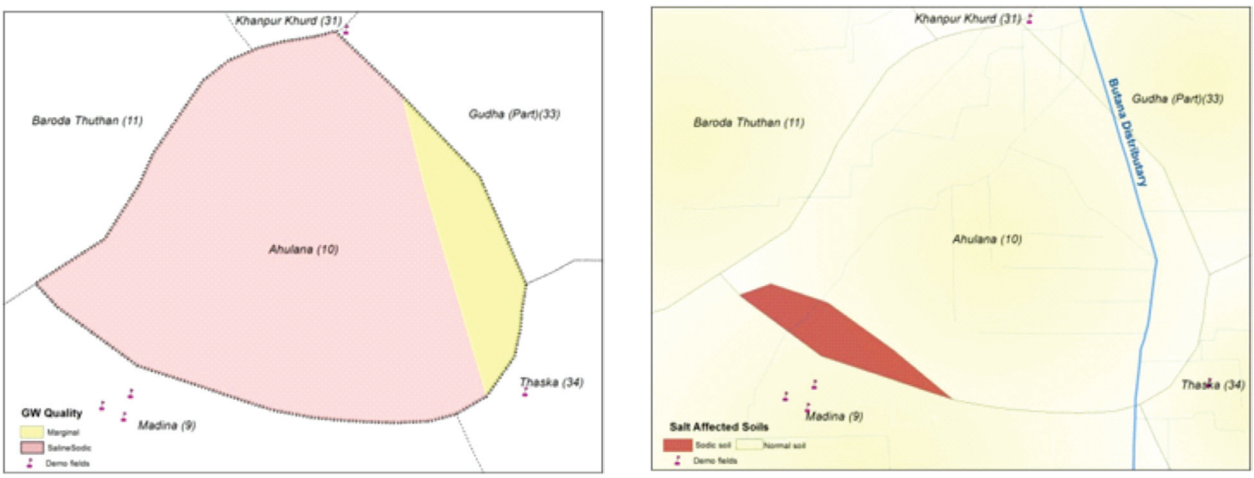


Fig. 9. Groundwater quality and salt-affected soils in Ahulana village (mid reach)

Fig. 10. Groundwater quality and salt-affected soils in Sanghi village (tail reach)

Table 6. Area under groundwater quality and salt-affected soils in three selected villages

Village	Reach	Area under each class (%)			
		Salt-affected soils		Groundwater quality	
		Normal	Sodic soil	Marginal	Saline-sodic
Gangana	Head	2.5	97.5	65.6	34.4
Ahulana	Mid	94.4	5.6	11.4	88.6
Sanghi	Tail	100.0	0.0	0.0	100.0

Table 7. Sociological information of three villages

Head	Gangana	Ahulana	Sanghi
Location in canal reach	Head	Mid	Tail
Total households (No)	1080	1044	1435
Total population	6470	6254	8357
Total male population	3581	3438	4529
Total female population	2889	2816	3828
SC population	906	813	938
SC male population	471	431	490
SC female population	435	382	448
Village area (ha)	1917	1092	2274

Delineation of area of low productivity

The geodatabase was further used for the identification and delineation of area of low productivity in the WYC Command adopting a GIS protocol (Fig. 11). The protocol was developed by using the data of canal supply status, groundwater quality, salt affected soil classes, satellite derived normalized difference vegetation index (NDVI), normalized difference salinity index (NDSI) and normalized difference waterlogging index (NDWI). It was found that about 7.24% of the WYC Command was affected with low productivity (988.9 km^2) district-wise during the year 2010 (Fig. 12), which has received the rainfall depth more than 119% of the normal annual rainfall. The low productivity/salt affected area has increased substantially during deficient rainfall years. Six key thematic layers of the *Geodatabase* viz. monsoonal rainfall departure, canal supply, groundwater quality, salt-affected soils, soil texture and village information were queried for multi- features/ attributes using criteria such as average rainfall, adequacy of canal supplies, groundwater quality class, saline/sodic soils, soil texture class, and village information. Thus, the area of crop production constraints in saline environments was identifid. These constraints prevailed in the large parts of Rohtak, Jind, Sonipat, and Hisar districts (Fig. 12). This has helped to assess resource constraints in order to predict the relative crop yield loss at farm level in saline environment using crop-water-salinity-yield response functions and to recommend the BMP based interventions for minimizing yield loss in the command.

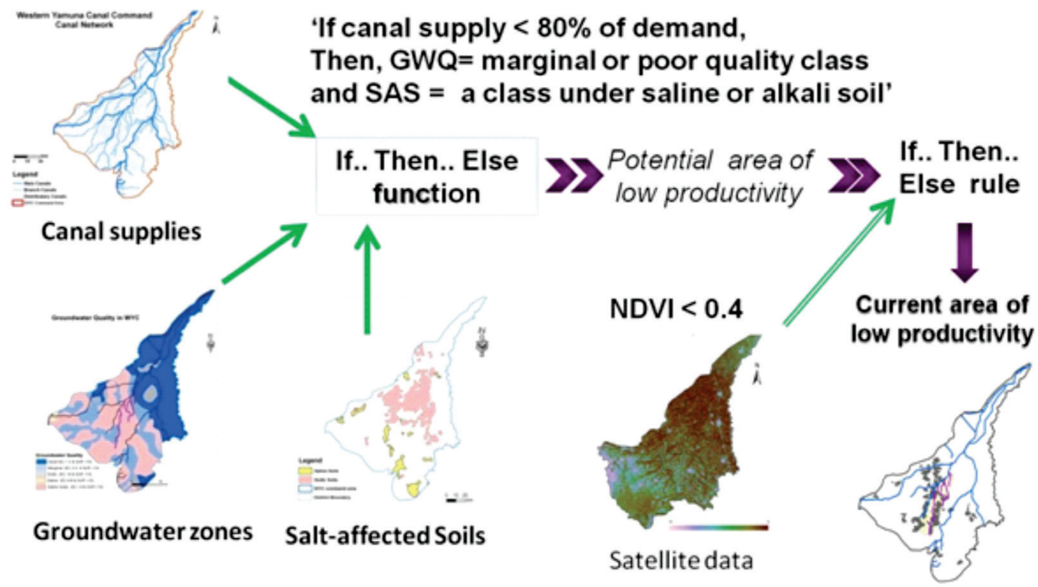


Fig. 11. GIS based protocol for identification and delineation of area of low productivity

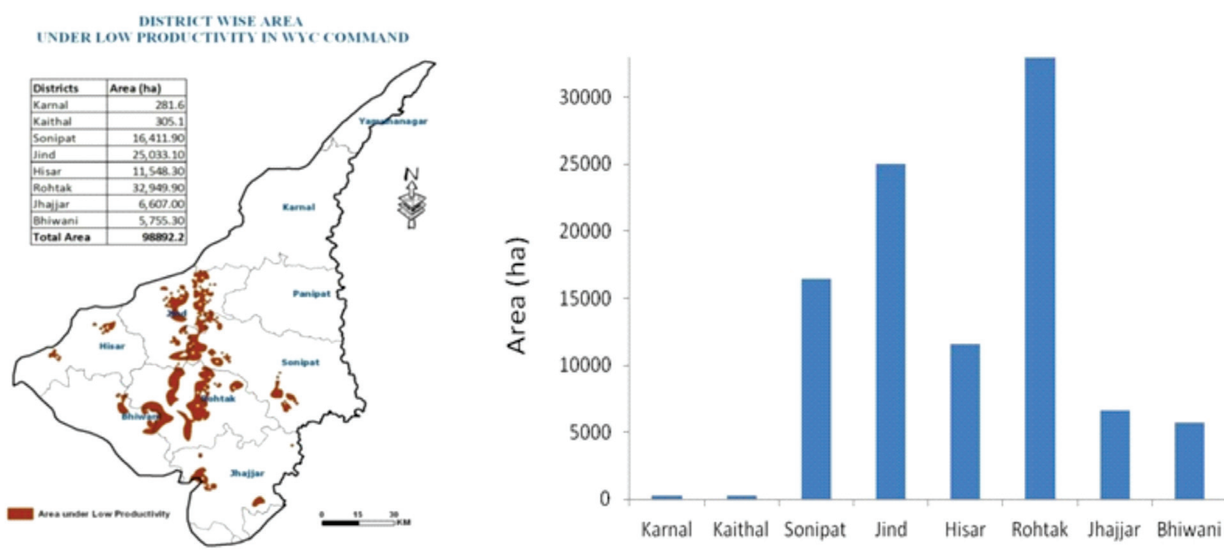


Fig. 12. District-wise area of low productivity in the WYC Command

Migration of database to open source platform for free distribution and online sharing

Since the database originally developed in the ESRI's ArcGIS proprietary format (Geodatabase) could not be queried and displayed directly by any open source GIS software, the database was migrated to an open source software platform, QuantumGIS version 1.7.4, which has allowed free distribution of the database and software to the stakeholders/ users for querying and generating value added maps (Fig. 13). The geodatabase could be shared online through ESRI's geospatial web server (ArcServer), which is exorbitantly expensive to deploy (₹ 25 lakhs). For online querying through open source software, the database was further migrated to PostGIS and GeoServer to publish and disseminate over the web with leading geoportals on the basis of interoperability using open standards.

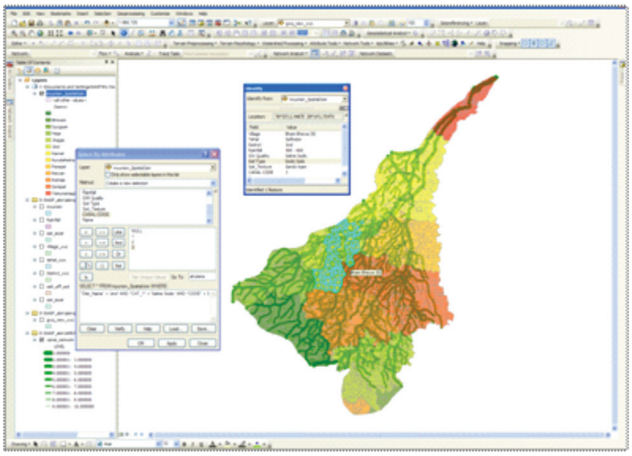
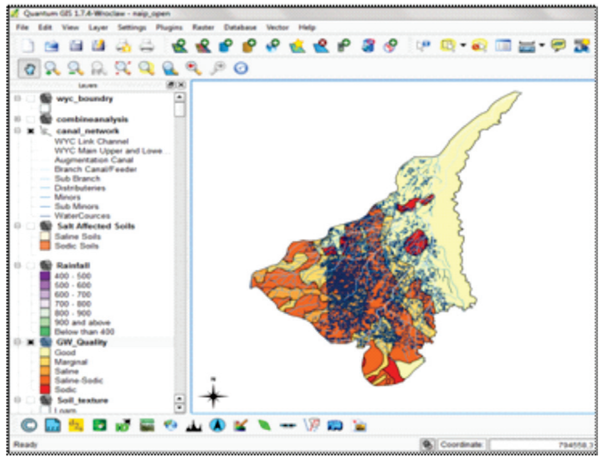



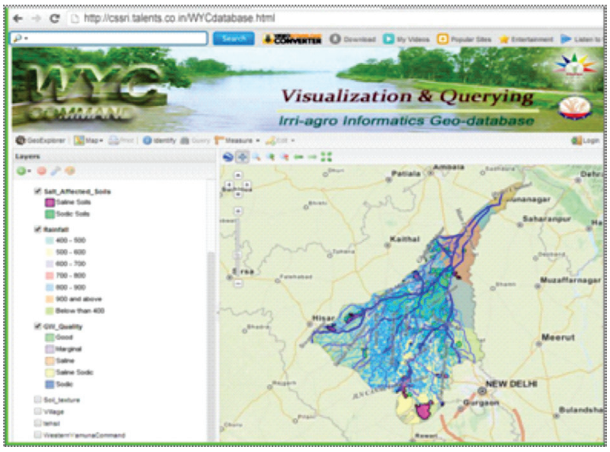
Fig. 13. Migration of developed database from ArcGIS to Quantum GIS for free distribution

A web map service of the *Irri-agro Informatics GIS database* of the WYC Command was developed using open source GeoServer software v2.3.0 for online visualization and querying of thematic vector layers over the web for use by stakeholders (Fig. 14). This has made the developed database compatible and comparable in terms of quality and geometry for further use to the stakeholders. This has functionalities of querying using feature identity tools for single or multi layers. This service has made querying from single layer or multi layers (rainfall /groundwater quality/salt-affected soil/soil texture/canal layer) with single or multi attribute (groundwater quality class/ salt-affected soil class/ soil texture class) (Fig. 14a-14d). This online service was made available to stakeholders through the project website. The six thematic layers of the database were displayed with Google earth® for use by stakeholders (Fig. 14) for identifying resource constraints for crop production at farm level- low canal supply, saline soils and poor quality groundwater. This has also helped to predict the yield loss under different constraints as well as to generate BMPs for sustaining/enhancing crop yield.

Objective 2

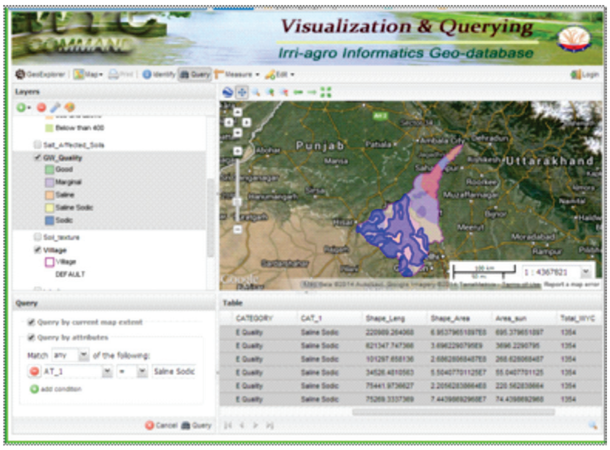
➢ **Upscaling of wheat yield from field to command scale**

Wheat yield data from 290 crop cutting samples collected from the demonstration and monitoring fields in the WYC command using GPS handset, and wheat yield data from Agriculture Department, Haryana were correlated with temporal NDVI spectral profile generated from three Resourcesat-1 LISS-3 imageries (19 December, 5 February and 11 March) during the rabi season 2010-11. These data were analysed and compared using GIS with spectral vegetation, salinity and waterlogging indices (NDVI, NDSI and NDWI) values and were upscaled to generate yield variation map of wheat crop of the WYC Command using regression technique (Fig. 15). The wheat yield ranged from 3.51 to 4.75 t ha^{-1} and the variation in upscaled yield data was verified with ground truth data and was found to be reasonable good. The yield less than 4.0 t ha^{-1} was reported in 56% area of the command which lies in parts of Sonipat, Jind, Rohtak, Hisar Jhajjar and Bhiwani districts. The highest yield of ~5.0 t ha^{-1} was observed in Indri block of Karnal district.

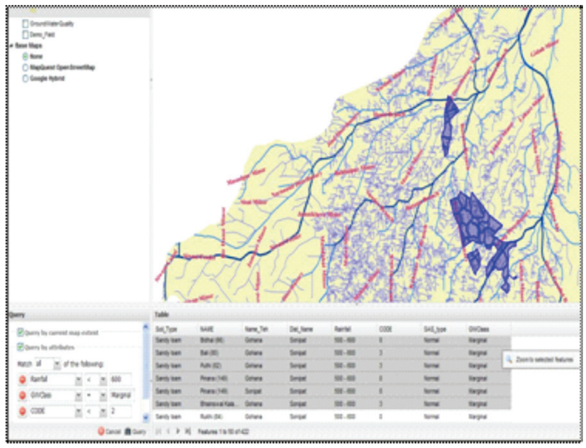


(a)

(b)



(c)



(d)

Fig. 14. Online dissemination of the database overlaid with Google (a), district-wise spatial querying (b), GW quality layer querying (c), and multi layer and attribute querying (d)

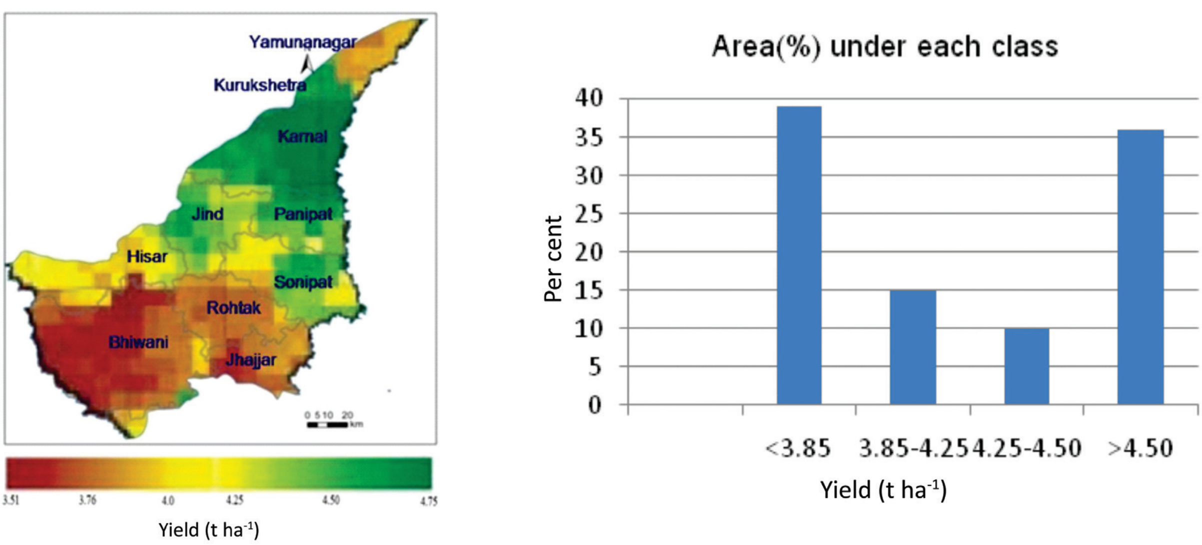


Fig. 15. Variation in upscaled wheat yield from head to tail in the WYC command

The wheat yield data for 12 districts under the WYC command for the last three years were collected from Agriculture Department, Haryana. It was found that the highest yield of wheat (>5 t ha^{-1}) was obtained in 2011-12 with slightly lower yield in Bhiwani, Jhajjar and Gurgaon (Fig. 16). Whereas good yield was obtained during 2010-11 in Bhiwani, Jhajjar, Gurgaon and Rewari districts due to normal monsoonal rainfall.

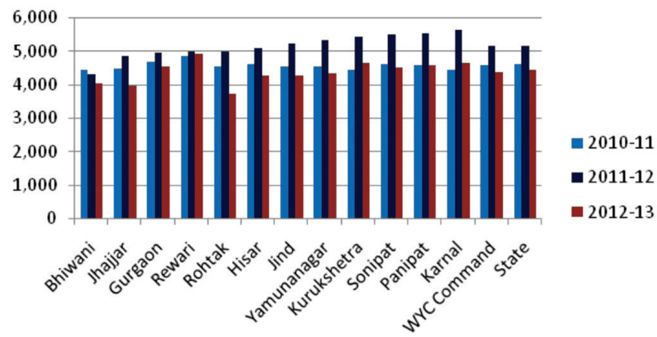


Fig. 16. District-wise distribution of wheat yield in the WYC command from 2010-11 to 2012-13

- **Performance evaluation of AquaCrop and SWAP models and development of salinity production function**

Modelling wheat yield, water productivity and salt dynamics using AquaCrop

Water driven crop growth models of varying complexity of saline environments are necessary for simulating grain and biomass yields, and water productivity of different crops under varying saline irrigation regimes and these models could be integrated into DSS main user interface under Modelling menu. These models are the appropriate tools to understand crop yield and productivity trends under future climate and irrigation water supply scenarios. This study was undertaken to simulate the grain yield and water productivity of four wheat varieties, including 3 salt-tolerant (KRL-19, 1-4; 210) and one salt non-tolerant variety (HD-2894) grown under different salinity levels using the water-driven AquaCrop ver. 4.0 with salinity functionality released during June 2012 (Fig. 17). The experiment was conducted at the research farm of WTC, New Delhi during

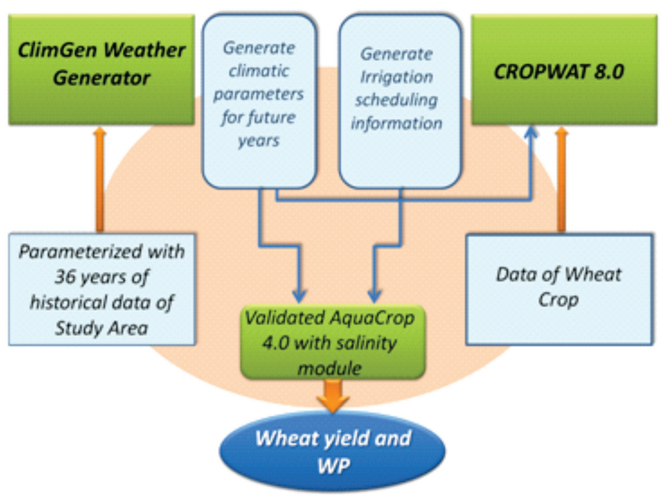


Fig. 17 Schematic architecture of ClimGen-CROPWAT and AquaCrop models to generate future yield of wheat under variable water availability scenarios.

rabi 2009-10 and 2010-11. The AquaCrop model was calibrated for simulating grain yield, biomass yield and water productivity for four wheat varieties (KRL-19, 1-4; and 210 and HD-2894), and four irrigation water salinity regimes (1.5, 4, 8 and 12 dS m^{-1}) from experiment data of *Rabi* 2009-10 and validated with the data of *Rabi* 2010-11. The accuracy of model prediction was evaluated by estimating model efficiency (ME), index of agreement (d) and coefficient of determination (R^2) comparing between the observed and the model simulated results. The calibrated model resulted in the prediction error statistics- ME, d and R^2 of 0.99 each for grain yield; 0.55, 0.98 and 0.91 for biomass, and 0.27, 0.98 and 0.99 for water productivity, respectively, for different wheat varieties and salinity levels. The validated model error statistics- ME, d and R^2 for grain yield was 0.85, 0.96, 0.94; and for biomass 0.70, 0.95, 0.95, respectively, for all varieties and salinity levels (Fig. 18). However, AquaCrop model predictions were the best for the grain yield, better for the biomass and relatively inferior for water productivity for all wheat varieties and salinity levels.

Further, the validated model was linked with CROPWAT and ClimGen to estimate the irrigation water requirement to obtain yields of wheat under full and deficit irrigation, and rainfed conditions (Fig. 17). Overall, the grain yield and biomass predictions by AquaCrop model for salt tolerant wheat varieties under irrigated saline regimes were observed to be better than the salt non-tolerant variety HD-2894. This may be attributable to the reduction in yield of salt non-tolerant wheat variety with saline irrigation having higher salinity levels. Moreover, the prime advantage of using AquaCrop model is that it required lesser number of inputs data in simulating the wheat growth and yield under different saline irrigation availability scenarios, as compared to other crop growth models. Nonetheless, from the results of field experiment and modelling, it can be concluded that the water driven FAO AquaCrop model could be used to predict the wheat yield with acceptable accuracy under variable saline irrigation and field management situations in the WYC command and semi-arid regions of northern India. The simulation results under different irrigation water availability scenarios in the canal command pertaining to wheat yield were used in the database of DSS program.

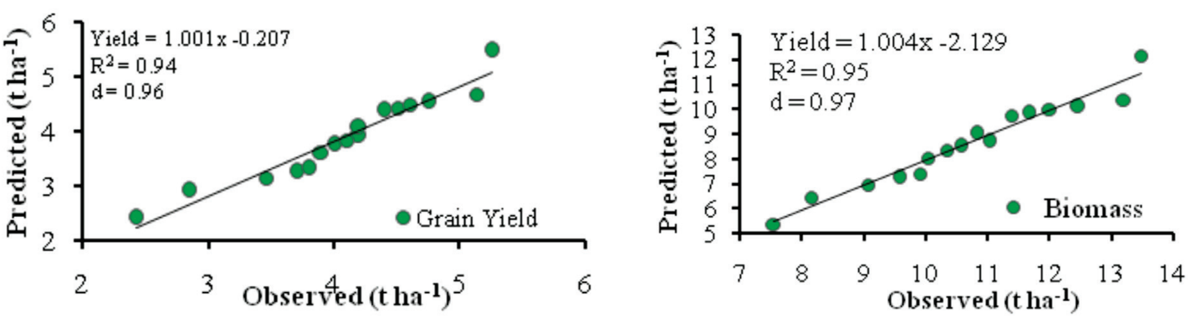


Fig. 18. Model validation results in simulating grain yield and biomass yield of wheat

Modelling grain yield and rootzone salt dynamics using SWAP

In order to simulate the water and salt dynamics in crop rootzone and the relative yield of salt tolerant and salt non-tolerant wheat varieties, the process based Soil-Water-Atmosphere and Plant (SWAP) model was used which is designed to simulate flow and transport processes at field scale, during growing seasons, for cropping systems and for long-term time series under saline irrigation environment. It offers a wide range of possibilities to address both research and field questions of irrigated agriculture, water and salinity management and environmental protection. The model employs the Richard's equation including root water extraction to simulate soil moisture movement in variably saturated soils. Basic processes of convection, dispersion, adsorption and decomposition are used for solute transport. The generic crop growth module, WOFOST is incorporated to simulate leaf photosynthesis and crop growth. The soil moisture, heat and solute modules exchange the status information in each time step to account for all kind of interactions. Crop growth is affected by the actual soil moisture and salinity status on a daily basis.

The SWAP model was calibrated and validated for three different salt tolerant wheat varieties (KRL-1-4, 19 and 210) and one salt non-tolerant variety (HD-2894) using the experiment generated data acquired at WTC farm under four irrigation treatments *viz.* groundwater (S_1), and saline water levels of 4 (S_2), 8 (S_3) and 12 dS m^{-1} (S_4) for *rabi* 2009-10 and 2010-11 cropping seasons, respectively. The model performance indicators *i.e.* model efficiency (ME) and degree of agreement (d) was 0.76 and 0.93 for root zone soil salinity and 0.96 and 0.99 for relative wheat yield of the calibrated model, respectively. Furthermore, root mean square error (RMSE) and mean absolute error (MAE) for prediction of relative yield during calibration was 4% and 3% and during validation was 9.6% and 8.3%, respectively. The validated model performed well for salt dynamics in root zone and relative yields that were corroborated by prediction error statistics R^2 of 0.96 and 0.95, ME of 0.95 and 0.75 besides degree of agreement (d) of 0.98 and 0.93, respectively. It was observed that the model performed better for prediction of relative yield of salt tolerant varieties as compared to the salt non-tolerant variety under different saline irrigation regimes. Overall, the SWAP model could be used to simulate the salt dynamics in the crop rootzone and yield of wheat with acceptable accuracy under irrigated saline environment (Fig. 19).

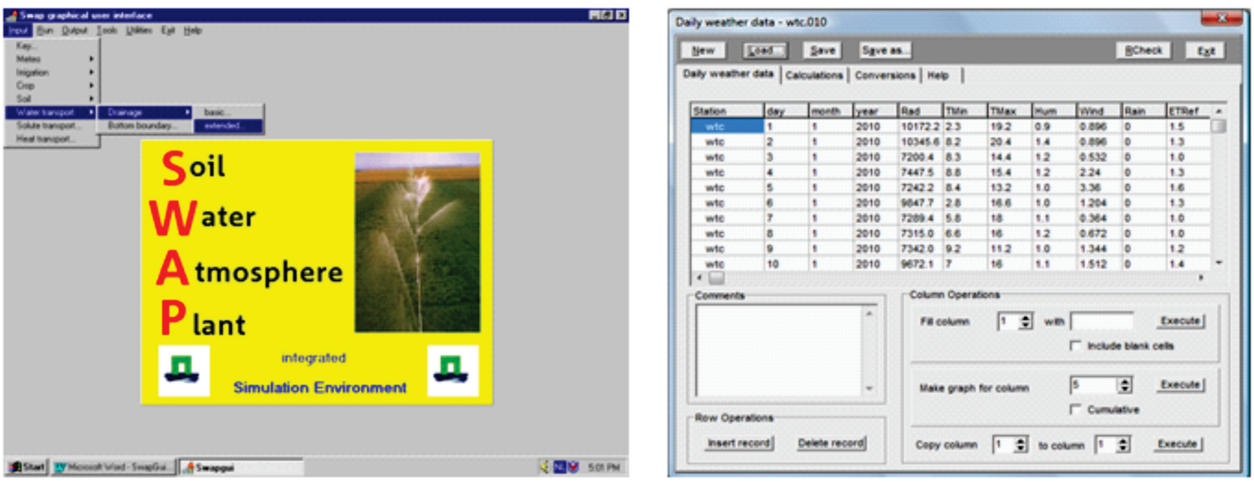


Fig. 19. Captured screens of SWAP model and data input interface

The soil hydraulic properties and crop and irrigation parameters of the study area (Table 8 & 9) were used in SWAP model for calculation of solute transport (Table 10).

Table. 8. Mualem Van Genuchten parameters describing the soil hydraulic properties

Soil	Topsoil (cm)			Subsoil (cm)	
	0-15	15-30	30-45	45-60	60-90
Depth of layer (cm)	15	15	15	15	30
Soil texture	Sandy loam	Sandy loam	Loam	Loam	Clay loam
Residual water content, θ_{res} (cm^3 cm^{-3})	0.01	0.01	0.01	0.01	0.01
Saturated water content, θ_{sat} (cm^3 cm^{-3})	0.36	0.34	0.29	0.37	0.31
Shape parameters, α (per cm)	0.052	0.054	0.027	0.039	0.026
Shape parameters, n	1.16	1.15	1.08	1.09	1.07
Shape parameters, λ	0.50	0.50	0.50	0.50	0.50
Saturated hydraulic conductivity, K_S (m day^{-1})	33.52	31.03	11.12	6.64	3.94

Source: Hirekhan *et al*. (2007) and value selected from the proposed range suggested in the SWAP model

During the model calibration process, the sensitivity of different input parameters were observed (Table 11). The crop emergence date, crop height, LAI, root depth, initial soil salinity at different soil depths, reference evapotranspiration, depth of rainfall, irrigation scheduling and irrigation water salinity were highly sensitive to model input parameters. Whereas, the canopy resistance, threshold EC, root water uptake, precipitation interception coefficient, dispersion length, diffusion coefficient and irrigation methods were moderately sensitive parameters observed during the calibration process.

Table 9. Crop and irrigation data used in SWAP model

General	
Simulation period	Dec 2009-Apr 2010; Dec 2010 - Apr 2011
Crop	Wheat cultivars (KRL-1-4, 19, 210 and HD-2894)
Irrigation water quantity (mm)	258#, 250*
EC of pre-sowing irrigation water (dS m^{-1})	1.45#, 1.70*
Crop specific (Wheat)	
Length of crop cycle (days)	127#,127*
Maximum crop height (cm)	98
Maximum rooting depth (cm)	100
h_1, h_2, h_{3h}, h_{3l}, h_4 (cm)**	-0.1, -1, -500, -900, -2000
Threshold EC_e (dS m^{-1})	2
Slope (% per dS m^{-1})	4.5
Minimum canopy resistance (S m^{-1})	0.7
Precipitation interception coefficient (cm)	0.25
Extinction of light within the canopy	
Extinction coefficient for diffused visible light	0.35
Extinction coefficient for direct visible light	0.65

in 2009-10 * in 2010-11

** Parameters of Feddes function adjusted as per value suggested by Wesseling *et al.* (1991) and Taylor and Ashcroft (1972)

Table 10. Parameters for the calculation of solute transport

Site (WTC03 farm)	2009	2010
Initial soil EC_e (dS m^{-1})		
Compartment 1 (0-15 cm)	0.256	0.25
Compartment 2 (15-30 cm)	0.198	0.197
Compartment 3 (30-45 cm)	0.23	0.233
Compartment 4 (45-60 cm)	0.346	0.342
Compartment 5 (60-90 cm)	0.493	0.495
Initial groundwater EC_{iw} (dS m^{-1})	1.45	1.70
Dispersion length, α_L (cm)	25	
Diffusion coeff. in water, D_w (cm^2 day^{-1})	1.5	

Source: Adjusted within the range suggested by SWAP model

Table 11. Sensitivity of SWAP model to different input parameters in simulating the salt dynamics and wheat yield under irrigated saline environment

High Sensitivity	Moderate sensitivity	Low sensitivity
	Crop inputs	
Date of crop emergence	Harvest date	Crop cycle
Extinction coefficients within the canopy (diffuse visible light and direct visible light)	Minimum canopy resistance	Precipitation interception coefficient
Leaf area index	Threshold EC_e (dS m^{-1})	Threshold level atmosphere demand (high and low)
Crop height	Root water uptake (slope % per dS m^{-1})	
Root depth	Precipitation interception coefficient	
	Soil inputs	
Initial soil salinity at different soil depths	Soil texture	Maximum thickness of ponding water
	Dispersion length	Relative uptake of solute of root
	Diffusion coefficient in water	
	Climate inputs	
ET_{ref}, rainfall		
	Irrigation	
Irrigation time, irrigation salinity, irrigation depth	Irrigation methods	

SWAP model validation for prediction of relative yield and rootzone salt dynamics

The model simulated and observed salinity profiles during model validation showed better trend and magnitude of soil salinity at harvest of wheat as that obtained during the model calibration process (Fig. 20 and 21). A close match with minimal deviation ascertained the capability of the SWAP model in simulating the salt dynamics in the root zone of wheat crop under irrigated saline environment. The higher soil salinity (5.45 dS m^{-1}) was observed up to 30 cm root zone depth and low salinity (2.5 dS m^{-1}) was simulated in 90 cm soil profile which was in line with the observed data (Fig. 21). The model simulated and observed values for all treatment combinations showed a R^2 of 0.96. The model performance indicators- ME and d were observed to be 0.95 and 0.98, respectively, which indicated a close agreement between the predicted and observed data as reported by Willmott, 1984 and Moriasi *et al*., 2007. The values of RMSE (0.84 dS m^{-1}) and MAE (0.69 dS m^{-1}) for salinity profile were in line representing better model performance as reported by Singh *et al*. (2006), Hirekhan *et al*. (2007) and Verma *et al*. (2012).

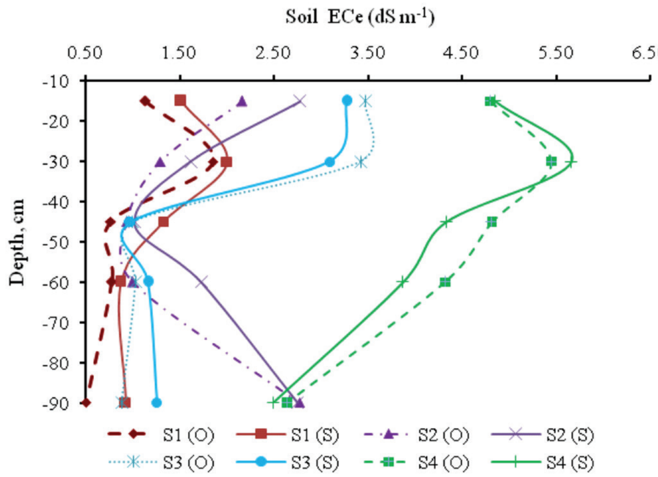


Fig. 20. Observed and simulated salinity profiles for different salinity levels of irrigation water at harvest of wheat crop during 2010-11

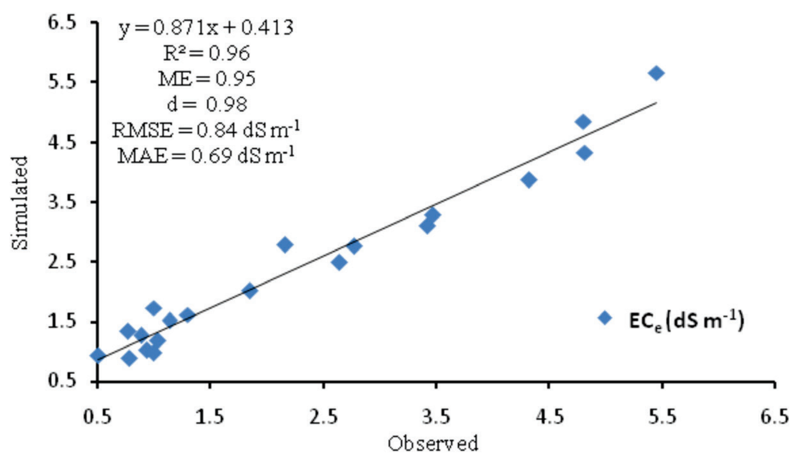


Fig. 21. Relation between simulated and observed EC_e of soil for all different treatments at harvest of wheat during 2010-11

The calibrated model was validated using the experiment data of *rabi* 2010-11. The validation results (Fig. 22) can be interpreted that the model underestimated the predicted relative yield for all varieties and salinity levels. For all treatment combinations, the model prediction error during model validation ranged from a minimum of 4% for S_1V_4 treatment to the maximum prediction error of 30% for S_3V_4. It was also observed that at lower salinity levels up to 4 dS m^{-1}, the prediction error ranged from 4 to 14 %, whereas for higher salinity levels of 8 and 12 dS m^{-1}, the prediction error varied from 6 to 30% for all varieties. Moreover, for salt tolerant varieties, the prediction error varied from 4 to 21%, whereas for the salt non-tolerant variety the prediction error varied from 4 to 30% for all salinity levels.

It was also observed that SWAP model performed better in prediction of the relative yield of KRL-1-4 (V_2) and KRL-19 (V_3) varieties for all salinity levels (Fig. 23). Moreover, the model prediction error under all salinity levels was the highest with a range of 4 to 30% for the salt non-tolerant

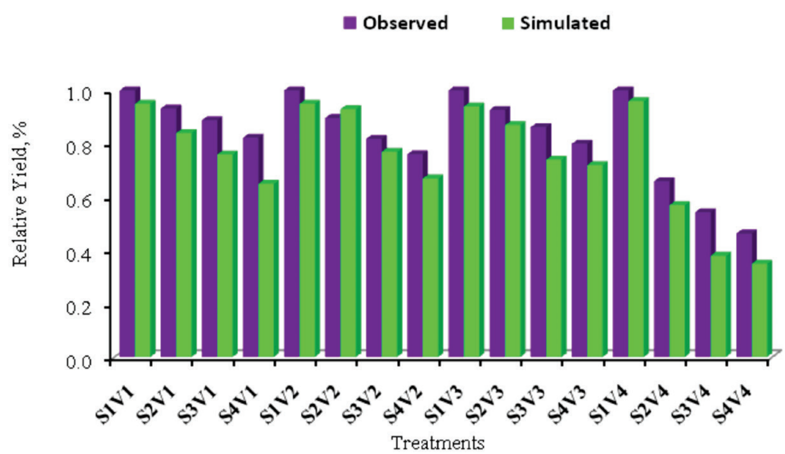


Fig. 22. The validation results of SWAP for all varieties at different salinity levels

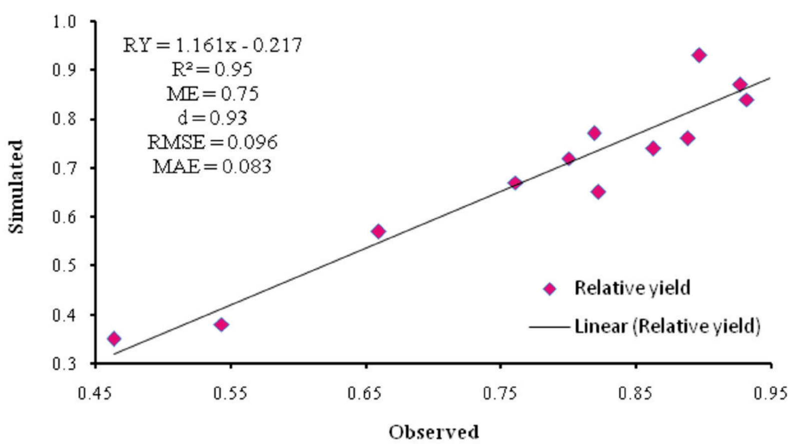


Fig. 23. Prediction error statistics of SWAP model validation for different varieties and salinity levels

variety (V_2). It was observed that the simple crop module of SWAP could able to predict the relative yield of salt tolerant wheat cultivars more accurately than the salt non-tolerant variety, HD-2894. Moreover, the model prediction error statistics R^2 was 0.95, ME was 0.75 and index of agreement (d) was 0.93 (Fig. 23) for all varieties and salinity treatments. The values of RMSE and MAE for relative yield prediction during model validation were observed to be 9.6% and 8.3% which was within the reported value pertaining to better model prediction as reported by Wahba *et al.* (2002); Verma *et al.* (2010) and Verma *et al.* (2012).

Performance evaluation of AquaCrop and SWAP for prediction of wheat yield and rootzone salinity

It was observed that both the AquaCrop and SWAP models could predict the yield with acceptable accuracy (Fig. 24; Table 12). Moreover, the AquaCrop model required minimal input data as compared to the SWAP model for simulation of grain yield of wheat cultivars. However, the soil salinity in the root zone profile was simulated more accurately by SWAP with prediction error statistics R^2 of 0.96, ME of 0.95 and d of 0.98 as compared to the AquaCrop model with R^2 of 0.53, ME of -1.12 and d of 0.74 (Table 13). Nonetheless, it was observed that both SWAP and AquaCrop model can be successfully used for simulation of salt dynamics and relative yield of both salt tolerant and non-tolerant wheat cultivars under saline irrigated regimes. However, with availability of limited data sets the AquaCrop model could be used to simulate the grain yield of wheat with the acceptable accuracy.

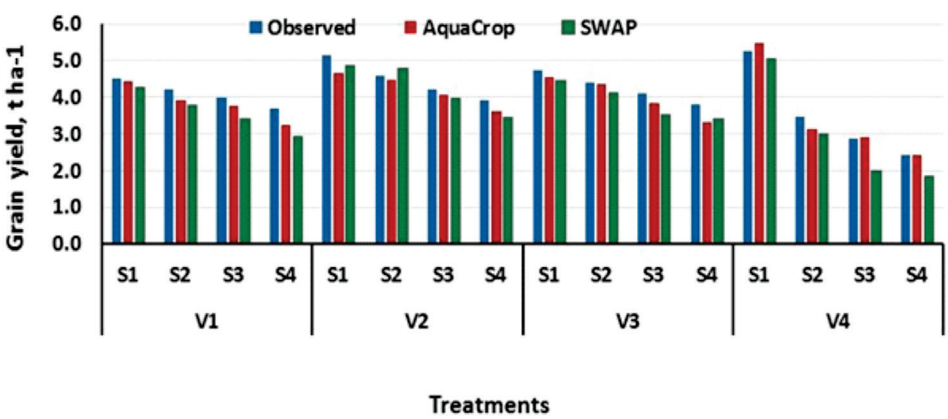


Fig. 24. Comparison of SWAP and AquaCrop simulated and observed data for grain yield

Table. 12. Comparison of prediction error statistics between SWAP and AquaCrop models for grain yield under all treatments

Model output parameter	Grain yield	
	SWAP model	AquaCrop model
Model efficiency (ME)	0.84	0.85
Index of agreement (d)	0.92	0.96
Coefficient of determination (R^2)	0.95	0.94

Table. 13. Comparison of prediction error statistics between SWAP and AquaCrop models for soil salinity in the root zone profile at crop harvesting

Model output parameter	Soil salinity	
	SWAP model	AquaCrop model
Model efficiency (ME)	0.95	-1.12
Index of agreement (d)	0.98	0.74
Coefficient of determination (R^2)	0.96	0.53

Development of salinity production functions using validated SWAP model

The validated SWAP model was used for prediction of grain yield of different salt tolerant and salt non-tolerant wheat varieties by inputting different irrigation water salinity ranging from 2 to 12 dS m^{-1} within the experiment range and also upto 16 dS m^{-1} (Fig. 25) for the salinity levels exceeding the experiment levels to simulate under situations where the irrigation water salinity is upto 16 dS m^{-1}. The relationship of relative grain yield of wheat and the irrigation water salinity in form of regression equations developed from such simulation by SWAP was used in the DSS program to generate alternative scenarios of relative grain yield of wheat and the yield loss at different salinity regimes.

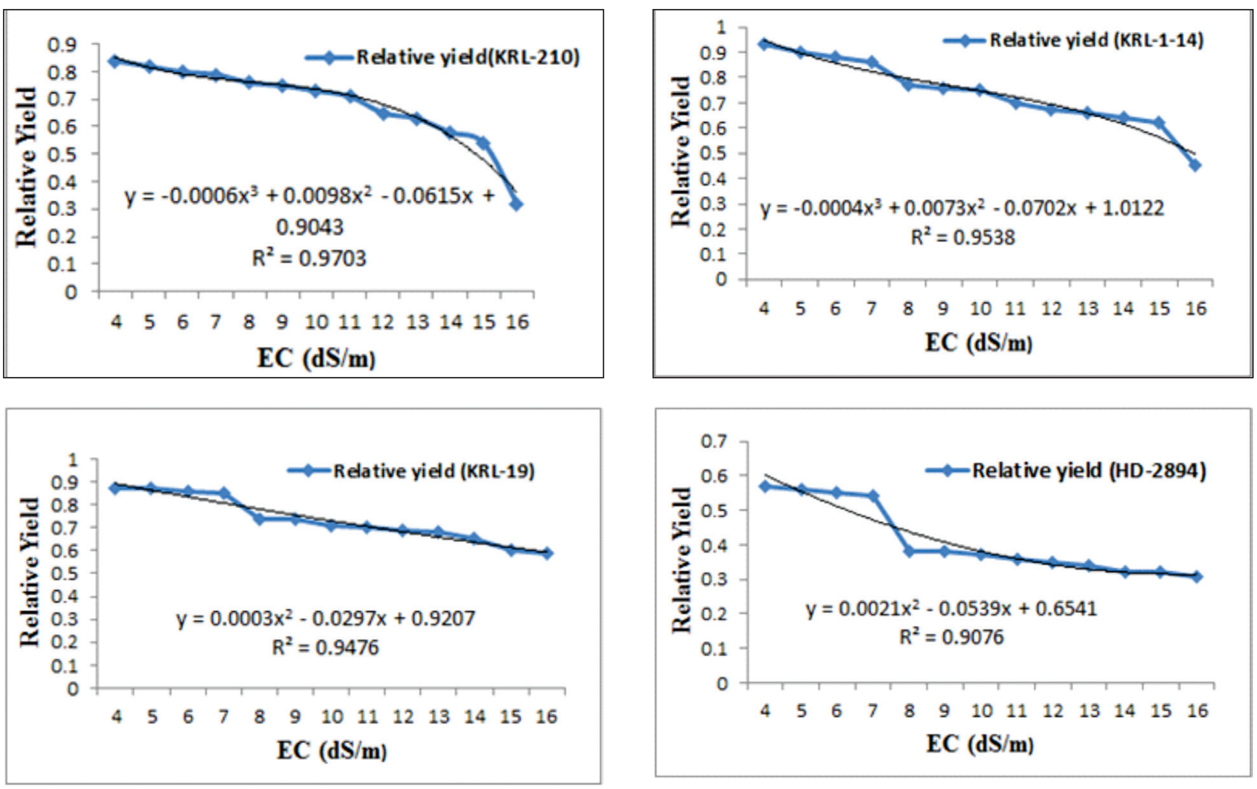


Fig. 25. SWAP model simulated relative yield of salt tolerant and non-salt tolerant wheat varieties under different irrigation water salinity regimes up to 16 dS m^{-1}

Impact of foliar potassium fertilizer on wheat yield under saline irrigation regimes

An experiment was conducted during *rabi* season 2010-11 to study the effect of foliar potassium fertilization at different crop growth stage in a ratio of 1:10 (K:Na) in water solution. The experiment

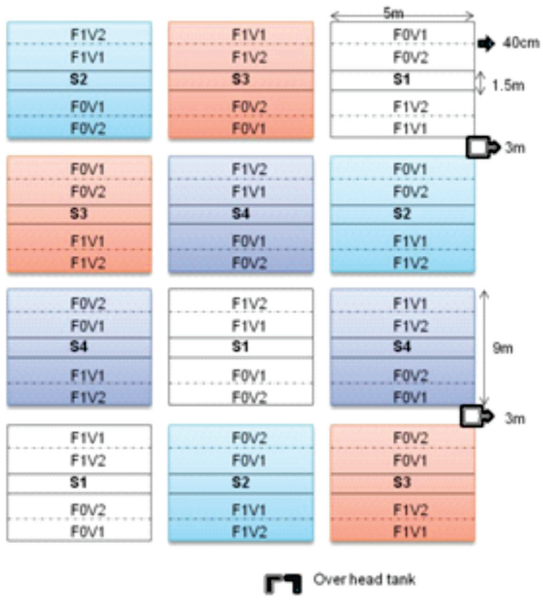


Fig. 26. Layout of the experiment on foliar potassium fertilization in wheat

undertaken during *rabi* 2011-12 was continued during *rabi* 2012-13 at WTC farm. The experiment was with an experimental design of double split plot with one salt tolerant wheat variety (KRL-1-4) and one salt non-tolerant variety (HD-2894) with and without foliar potassium fertilization under three different salinity levels (4, 8 and 12 dS m^{-1}) and control with groundwater having salinity of 1.7 dS m^{-1} (Fig. 26). It was observed from the data analysis of two years experiment that there was difference in yield with and without application of potassium fertilizer with foliar spray during three consecutive days at heading crop growth stage of wheat (during 54 to 65 DAS). It was observed that increase in the grain yield in both KRL-1-4 and HD-2894 with foliar potassium application as compared to the control was 22% and 15% higher, respectively, under irrigation water salinity of 8 dS m^{-1}. It was observed that the yield increase was from 1.7 to 8 dS m^{-1} salinity levels and reduced at 12 dS m^{-1} (Fig. 27) Also, KRL-1-4 resulted in higher grain yield as compared to HD-2894. Therefore, it can be concluded that based on the experiment data of two years experiment using artificial irrigation water salinity with low soil salinity, the application of foliar potassium fertilization could increase yield ranging from a minimum of 7 to 22% of salt tolerant variety,

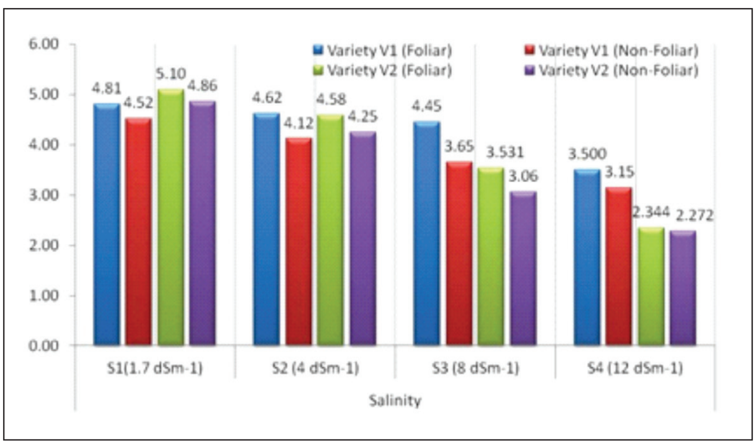


Fig. 27. Yield variation of wheat varieties V1- KRL-1-4 and V2 –HD-2894 under foliar and non-foliar potassium fertilization under irrigated saline environment

KRL-1-4, whereas the yield increase may vary from 3 to 15% for the salt non-tolerant variety, HD-2894. The highest increase of yield with irrigation water salinity of 8 dS m^{-1} was also observed during *rabi* 2010-11 experiment. However, the technology needs to be validated in farmers' field under saline soil and saline groundwater conditions for subsequent recommendations.

- **Crop water demand based canal schedule of Jhajjar distributary**

Crop water requirement varies according to climatic condition, crop type and variety, stage of crop growth, soil type etc. A realistic estimate of these parameters is essential for judicious irrigation scheduling which can lead to saving of water in water stress regions. Moreover, there exists a large spatial variation of these parameters in a canal command. Therefore, all these parameters need to be considered to generate a roster of canal water release in line with the crop water requirement of different crops grown in the command including the conveyance and other losses of water in the head, mid and tail reaches. In the study, the FAO's CROPWAT model was used for irrigation scheduling of different crops grown in the canal command (Fig. 28). The meteorological data of the area and the crop types were used in the FAO CROPWAT version 8.0 to estimate the crop evapotranspiration and subsequent irrigation requirement of crops and the total number of irrigations during the crop growth period.

In order to prepare the water delivery schedule of distributaries, a reverse estimation procedure was followed. The irrigation requirements of different crops in the canal command were calculated using the CROPWAT model. Subsequently, the irrigation scheduling was obtained from CROPWAT model using the desired information of soil characteristics and crop evapotranspiration. Besides this, the conveyance and other losses to supply water to head, mid and tail reaches were estimated in the canal command using the geospatial data. Further, the total volume of water to be released was estimated by using the irrigation scheduling depths, the cropped area and conveyance losses. All these estimated data were populated into the geospatial data base of the canal command at appropriate delivery points in the command. Moreover, the query building module of ArcGIS can provide the information of water supply at the outlet as desired by the user pertaining to different crops grown in the command which is fed by the selected distributary.

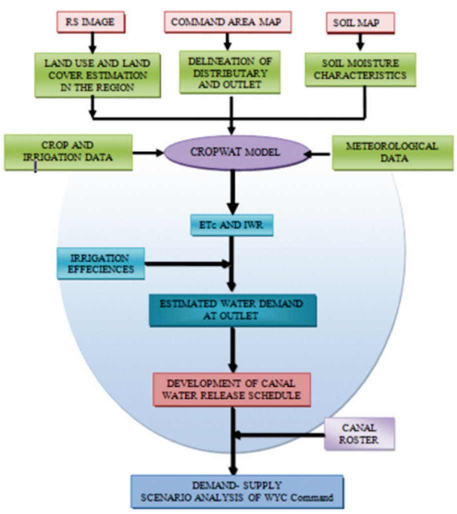


Fig. 28. Flow chart for arriving at demand-supply scenario of a distributary in WYC command

The information on the spatial variability of weather, soil, crop and canal flow rate from the database using GIS were input to CROPWAT model 8.0 to estimate the irrigation requirement of wheat and rice grown in the Jhajjar distributary command. An area of 5601 hectares was under rice-wheat cropping system in the distributary and the length of different canal segments in the network was obtained from the database (Fig. 29). It was observed that the irrigation requirement of wheat at field level was 254.6 mm and that of rice was 969.6 mm with effective rainfall depth of 55.8 and 461.8 mm during the wheat and rice growing seasons, respectively using CROPWAT. Further, the comparison of crop irrigation demand and canal supply as per the roster for twelve locations in the Jhajjar distributary showed that the canal supply as per roster is far less than the demand in majority of location points. Moreover, the data generation and analysis protocols developed for assessment of irrigation requirement can upscale from distributary to branch canal to entire WYC command and also replicate for other canal commands.

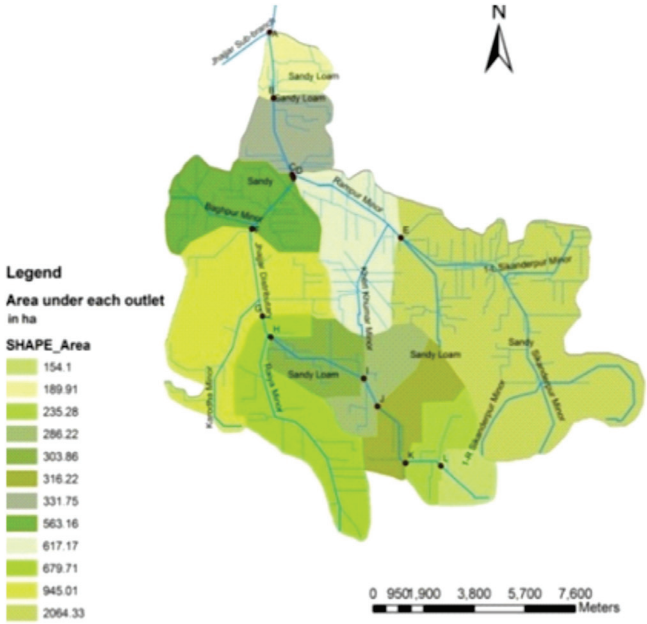


Fig. 29. Delineated command for each location (points A to L) in Jhajjar distributary

Objective 3

➢ **DSS Program for Enhancing Productivity in Irrigated Saline Environment**

Since one of the major deliverables of the sub-project was a standalone window based DSS application for use by state line departments, KVKs and progressive stakeholders, a standalone window based DSS program was developed in Microsoft C# programming language on .NET framework 3.5 platform by integrating database, key modules, crop-water-salinity-yield module, AquaCrop and SWAP to generate and evaluate the BMPs for various resource scenarios in saline environment for enhancing productivity (Fig. 30). The developed DSS application consists of six main modules - *Crop Water Demand*, *Canal Supply*, *Groundwater*, *Irrigation Scheduling*, *Modelling*, and *BMPs based Strategies,* and three supporting modules- *Database*, *Farmer*'s *Services* and *Help.* Six main modules were validated and debugged independently and then integrated into the main user interface. The *Database module* displays the eight spatial thematic layers and their attributes pertaining to the *Irri-agro Informatics Geodatabase* for assessing the farm scenarios/ constraints in saline environment.

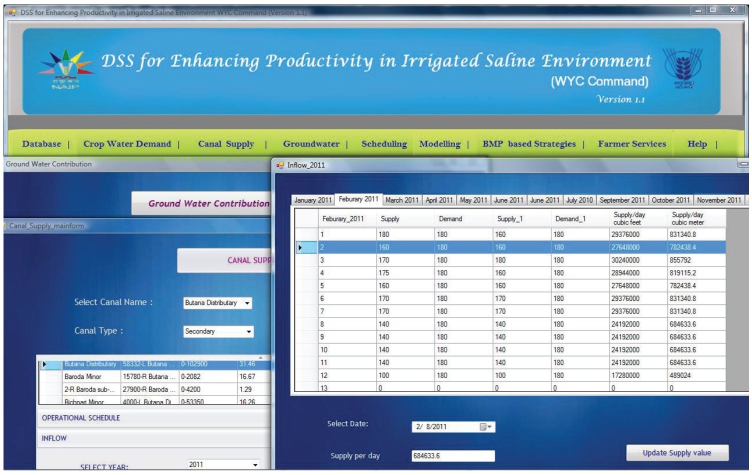
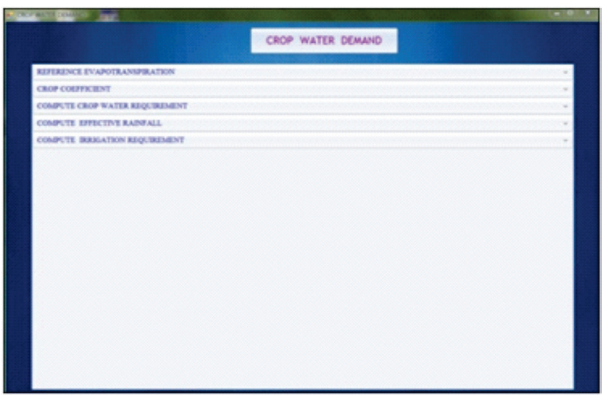
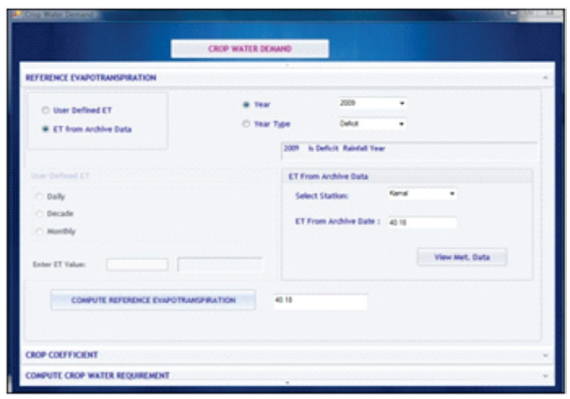


Fig. 30. Screen capture of DSS displaying canal supply in the WYC Command

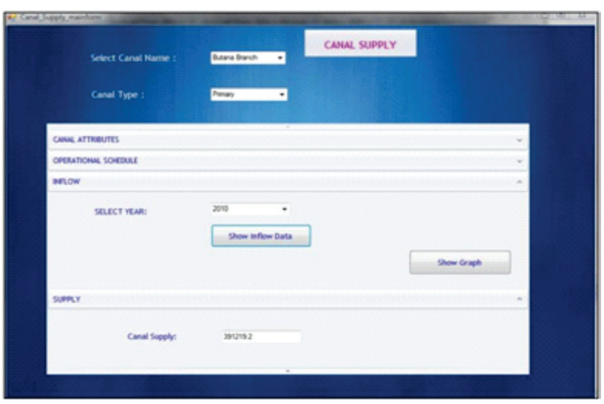
The *Crop Water Demand* module (Fig. 31a) was used to compute the reference crop evapotranspiration (ET_0) from daily weather data either user defined or from archived database from 2001 to 2013 using Penman-Monteith method. The reference crop ET was converted to crop ET by multiplying the weekly crop coefficient. The irrigation demand at watercourse outlet (Fig. 31b) was thus computed from water demand of various crop fields after subtracting effective rainfall and capillary water and



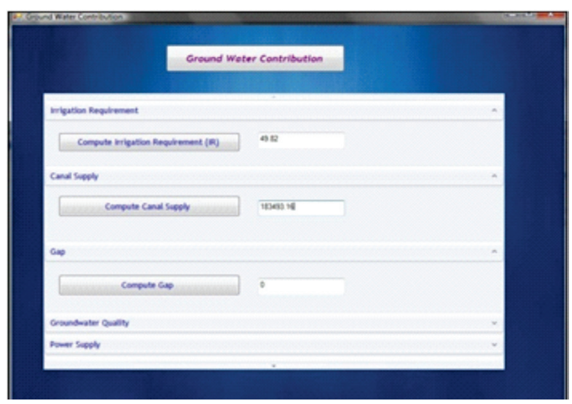
(a)



(b)



(c)



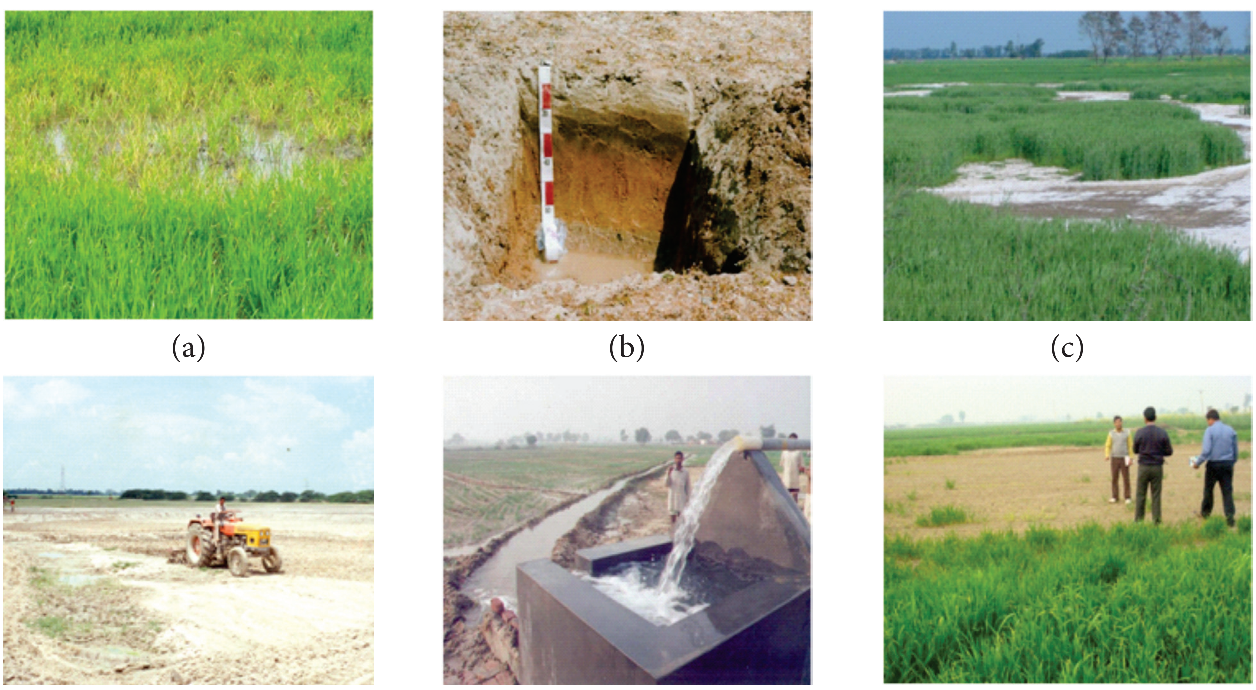
(d)

Fig. 31. Screen captured windows of modules of Crop Water Demand (a) with Reference Crop ET input interface (b), Canal Supply (c) and Groundwater (d)

adding conveyance and application loss. The *Canal Supply* module (Fig. 31c) has computed the canal supply and irrigation supply gap to meet full water demand of a crop. Whereas the *Groundwater* module (Fig. 31d) has computed the groundwater contribution to meet full irrigation demand. In *Irrigation Scheduling* module, irrigation schedules were generated for wheat and mustard crops for one of the following four irrigation options: (i) to maximize grain yield under conjunctive use of canal water/ good quality groundwater or both, (ii) to optimize grain yield under deficit irrigation or irrigation at critical phenological growth stages or allowed threshold water stress based on crop ET, (iii) to optimize crop yield under effective conjunctive use of canal water and marginal to poor quality saline/sodic waters, and (iv) to optimize grain yield under both water and salinity stresses. Three irrigation schedules were evaluated to maximize grain yield under conjunctive use of canal water and good quality groundwater or deficit irrigation as well as to minimize soil salinization. For use of marginal to moderate saline/sodic groundwater, suitable irrigation strategies with effective conjunctive use option were evaluated to optimize yield under different farm resource constraints.

Six saline environments viz., *water stagnation, waterlogging*, *soil salinity*, *soil sodicity*, use of *saline/ sodic tubewell water*, and *deficit irrigation* were prevailed in different reaches of the study Butana Branch in Sonipat and Rohtak districts, and Bhalaut Sub-branch in Rohtak and Jhajjar districts of WYC command (Fig. 32). These environments were observed during baseline data collection and subsequent field surveys. The crop production functions for different environments developed by CSSRI and from published literature were obtained for development crop-water-salinity-yield response module.

In *Modelling*, crop yield response module for prevailing six saline environments in the WYC command namely, *Surface water stagnation, Waterlogging*, *Soil salinity*, *Soil sodicity*, *Saline/sodic water irrigation*, and *Deficit irrigation* was developed to predict the crop yield loss in order to



(a) (b) (c)

(d) (e) (f)

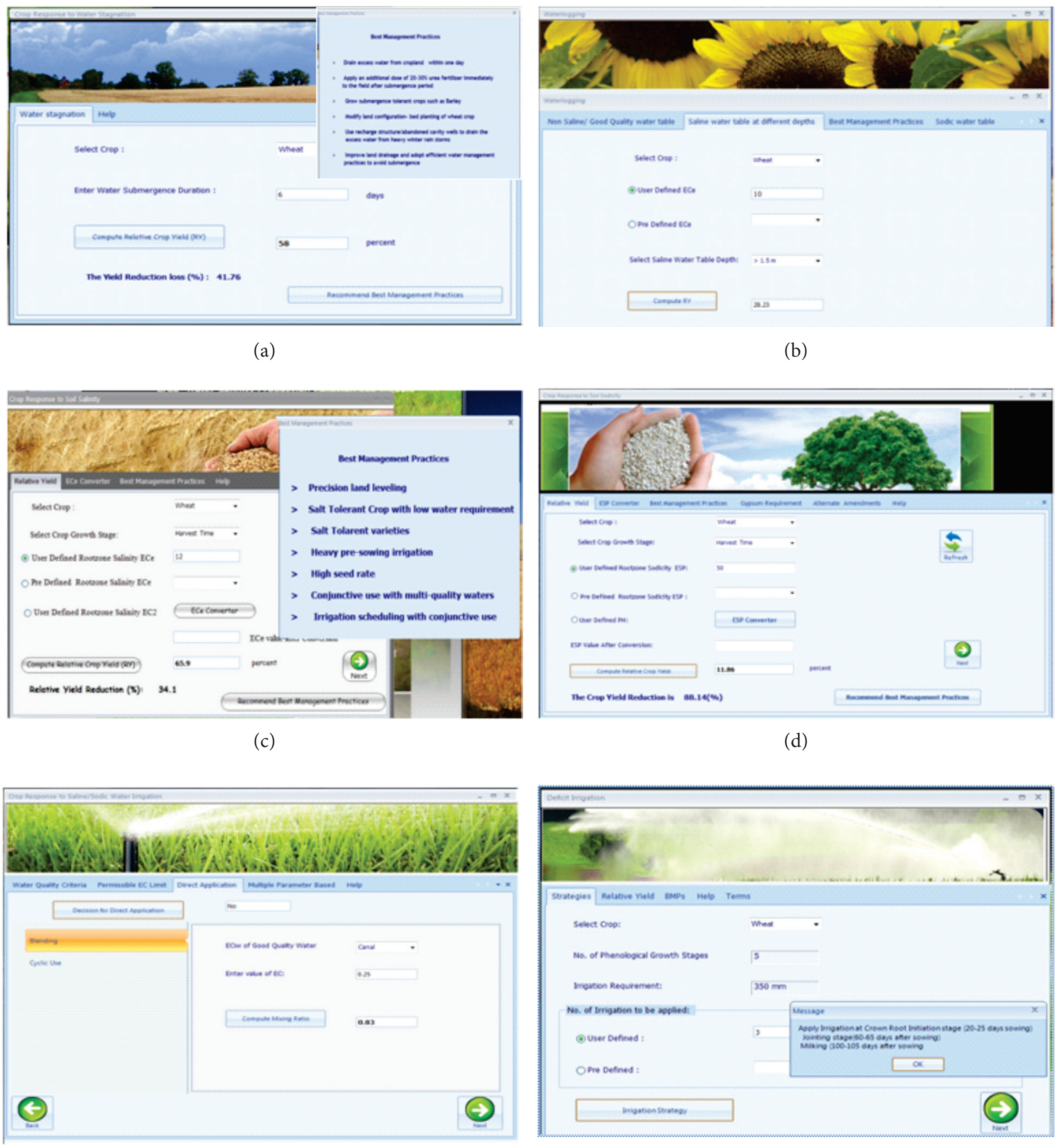
Fig. 32. Six prevailing saline environments in the WYC command (*Water stagnation, waterlogging*, *soil salinity*, *soil sodicity*, use of *saline/sodic tubewell water* and *deficit irrigation)*

recommend innovative best management practices (BMPs) for minimizing yield loss (Fig. 33). The module was tested and validated from the field data. In *Surface water stagnation* and *waterlogging* sub-modules, the crop yield loss for five crops (wheat, barley, mustard, pearlmillet and pigeon pea) was predicted for different short-term water stagnation periods and waterlogging and subsequently, suitable BMP recommendations were suggested for minimizing crop yield (Fig. 34 a and b). The short-term water stagnation and waterlogging conditions were resulted due to sodic nature of soils, excessive irrigation, seepage from distributaries, minors, and watercourses, and heavy winter rains, due to rise of water table and drainage congestion. These sub-modules have helped in minimizing crop yield loss.

Fig. 33. Screen captured window of crop-water-salinity-yield response module for six saline conditions

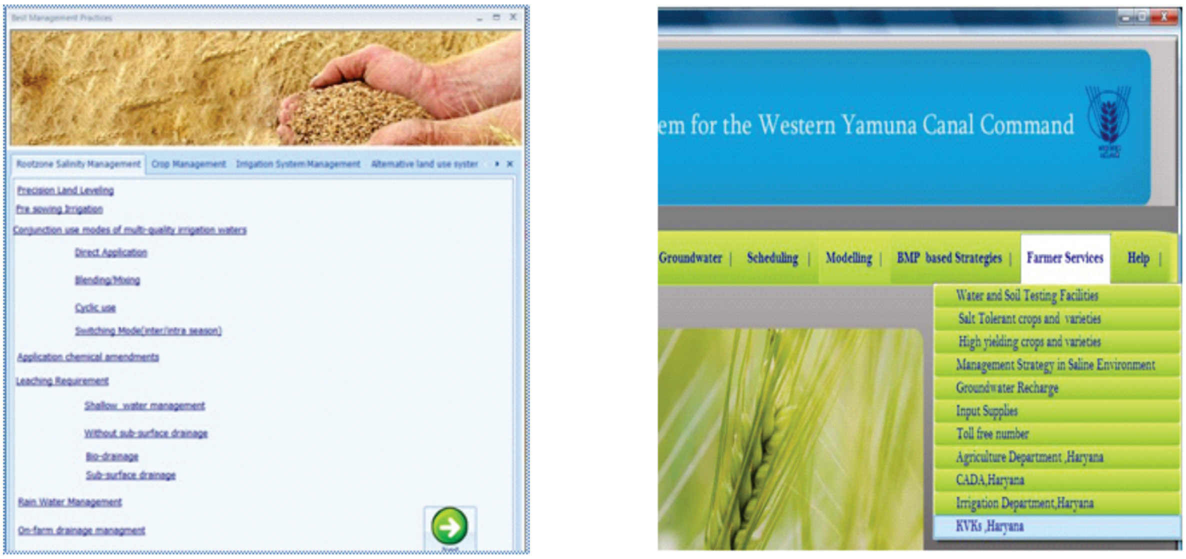
In *Soil Salinity* sub-module, relative crop yield loss was predicted for various rootzone salinities at different growth stages for five crops (wheat, barley, mustard, pearlmillet and pigeon pea). The suitable BMP for four salinity ranges (ECe < 4, 4-8, 8-12 and >12 dS m^{-1}) were recommended, respectively, for minimizing yield loss (Fig. 34c). Since soil ECe was mainly used in crop production function for saline conditions, the soil EC_2 was converted to soil ECe for predicting the yield loss. Whereas in *Soil Sodicity* sub-module, relative crop yield loss was predicted for different rootzone exchangeable sodium percentage (ESP) values for 6 *rabi* and *kharif* crops. The suitable BMPs for three ESP ranges (< 20, 20-50 and > 50%) were recommended, respectively, for minimizing yield loss (Fig. 34d). Since soil ESP was used crop production function for sodic conditions, the soil SAR, pHs and pH_2 were converted to soil ESP for predicting crop yield loss. The gypsum requirement (GR) was computed using Schoonover's formula and standard GR graph. The GR was also converted to equivalent amount of other chemical amendments required to reclaim sodic soils, if gypsum availability is reduced drastically in future.

In *Saline/sodic water irrigation* sub-module, water quality was assessed and the permissible limit of water salinity (ECiw) for different agro-climatic zones was identified. The relative crop yield loss was predicted for different irrigation water salinities for five crops (wheat, barley, mustard, pearlmillet and pigeon pea). The suitable BMP recommendations were suggested, respectively, for minimizing yield loss (Fig. 34e). In *Deficit Irrigation* sub-module, phenological growth stages for eight crops- wheat, barley, mustard, cotton, sunflower, sorghum, pearlmillet and pigeon pea were assessed and suitable irrigation strategy for different number of irrigations to be applied was suggested. The relative crop yield loss was predicted for five crops using three methods- tested production functions, Jensen's model and Stewart's model. The suitable BMP recommendations for different crops were suggested, respectively, for minimizing yield loss (Fig. 34f). In *BMP Interventions* sub-module, several BMP based strategies for controlling water stagnation, waterlogging, soil salinity and sodicity, sodic/saline water irrigation and deficit irrigation were generated and the detailed information on each BMP are provided for understanding quantitative impact of such BMPs (Fig. 35a). The farmer' services modules give general information to farmers on soil and water testing activities, salt tolerant and high yielding wheat crop varieties, link to state line department and KVKs (Fig. 35b).



(a) (b) (c) (d) (e) (f)

Fig. 34. Screen captures of *Surface water stagnation (a), Waterlogging (b), Soil salinity (c), Soil sodicity (d) Saline/sodic water irrigation (e),* and *Deficit irrigation* (f) sub-modules



(a) (b)

Fig. 35. Screen captured windows of BMP based strategies (a) and farmers' services module (b).

The WTC module was integrated to the DSS program main interface under Modelling dropdown menu. The module for enhancing crop yield under varying soil and water salinities was developed, debugged and populated with field experimental and published data to estimate the crop yield under foliar potassium fertilization and salt deposition in rootzone of wheat (Fig. 36). SWAP and AquaCrop models were also integrated with the WTC module to launch model application (Fig. 36). The DSS module was populated with secondary data, the SWAP model simulated results related to wheat yield under different salinity levels, and yield production functions. SWAP and AquaCrop model may be used where daily and weekly root zone salinity built-up and crop yield response is required, but these model need some of site specific parameters.

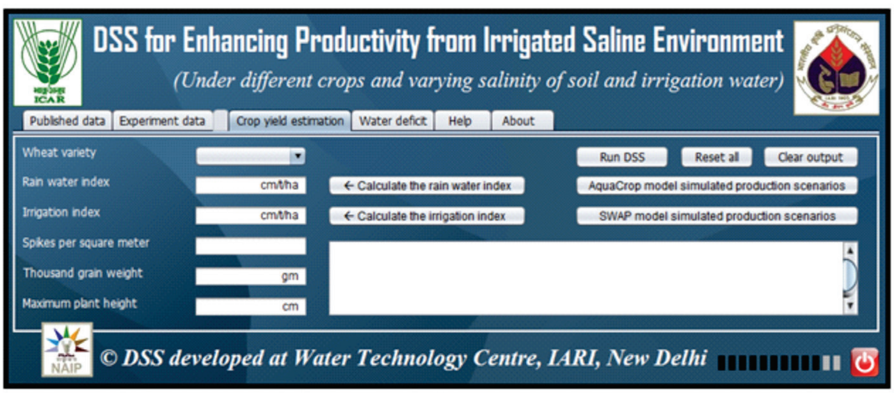
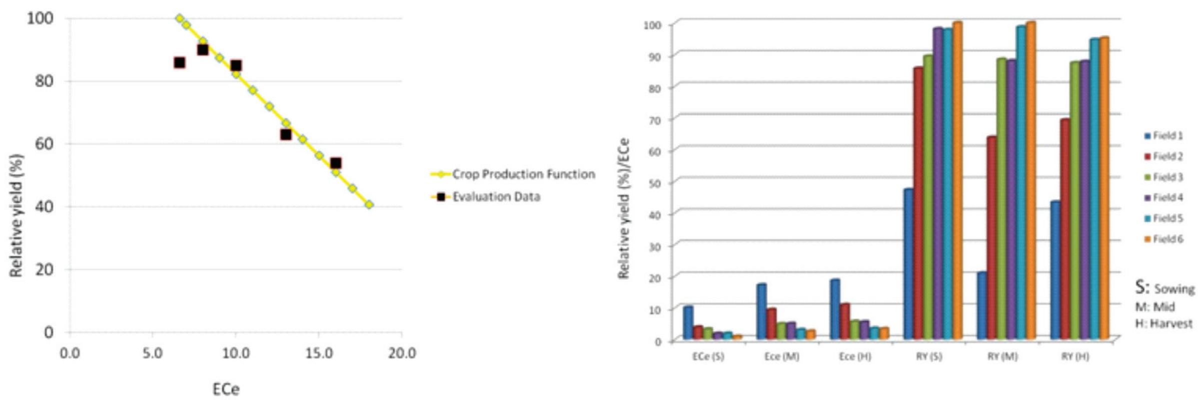


Fig. 36. Screen captured window of DSS for enhancing crop yield under varying salinity of soil and water in irrigated saline conditions developed at WTC, New Delhi

The crop production functions for soil salinity was validated with 5-6 sites and ECe data were collected at time of sowing, mid season and harvest time. The relative crop yield loss was predicted for various rootzone salinities at different growth stages for wheat (Fig. 37). The deviation in results with validated data was within the acceptable limit.

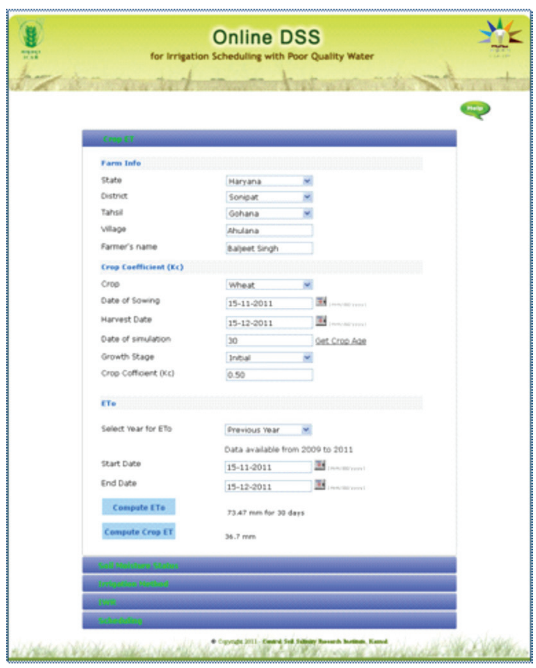


(a) (b)

Fig. 37. Evaluation of crop production functions with field data for wheat (a) and yield prediction of six fields with sowing, mid and harvest time ECe (b)

Customized DSS versions for various stakeholders

Three kinds of DSS programs were developed for targeting needs of different water authorities and water users in the WYC command. The standalone DSS has been described and screen captured window included in the above paragraphs and could be installed on a personal computer at district or sub-division offices of state departments/organizations and used for generating and BMPs for short-term water stagnation, waterlogging, soil salinity and sodicity, and use of saline/sodic water for irrigation and deficit irrigation. A GIS based custom DSS was developed by customizing the ArcGIS ArcMap interface through Microsoft .NET framework. This could be installed on a PC only which has got a run time license of ArcGIS software at least and is applicable to state line department



(www.cssri.talents.co.in)

Fig. 38. Screen captured window of Online DSS for irrigation scheduling with multi-quality waters

district offices where the required license are generally available. An online DSS is being developed for planning efficient irrigation schedule with cyclic conjunctive use of moderate saline or sodic groundwater for sustaining/enhancing crop yield and meeting the needs of state departments, canal water users associations and progressive farmers to evaluate alternate scenarios and BMPs generated by the online DSS. An online DSS was developed for planning efficient irrigation schedule with cyclic conjunctive use with moderate saline/sodic groundwater for meeting the needs of state departments, canal water users associations and progressive farmers to evaluate alternate scenarios and BMPs generated for increasing crop yield (Fig. 38). The Online DSS is available in the project website (www.cssri.talents.co.in) for use by interested users.

Support of Hindi to DSS Program

To cater the demand of canal water users' association members and progressive farmers, Hindi versions of DSS program and crop-water-salinity-yield response module were redeveloped to popularize its use among stakeholders as well as in state line departments (Fig. 39). To further expand its user base over web, a web DSS program in Hindi is being redeveloped from a standalone DSS for online dissemination to stakeholders. A framework for webDSS was developed for integrating database and six modules through GeoServer with compatible multiple web browsers. The web DSS would definitely meet the needs of state line departments and progressive farmers.

Fig. 39. Screen capture displaying Hindi version of DSS program and crop yield response module for popularizing among stakeholders

Objective 4

➢ **Field Demonstrations at Farmers' Fields**

Field demonstration at farmers' fields is necessary to win over the trust of farmers in DSS generated BMP based interventions and for validation of DSS module. Therefore, field demonstrations of wheat crop at 52 farmers' fields in Butana distributary (Fig. 40 and 41) and Jhajjar distributary in saline environment were conducted during 2010-11 and 2011-12 in Sonipat, Rohtak and Jhajjar districts to evaluate the six best management practices (BMPs)- four high yielding (HD-2967, 2891, 2894 and DBW-17) and three salt tolerant varieties, (KRL-1-4, 19, and 210), optimum irrigation scheduling, effective conjunctive use of moderate saline, SAR saline and high RSC sodic groundwater, zero tillage, laser land leveling and line sowing for enhancing crop yield. The wheat yield increased ranging from 17 to 33% in saline environments (Annexure-I, Table A.3) and improved the income of small farmers by ₹ 13,490-25,700 per hectare. These two distributaries were monitored during 2009-10 *rabi* season for demonstration in the next season. The field demonstrations have infused confidence in stakeholders on DSS generated solutions for quick adoption and the results of demonstrations were also used for validation of DSS modules.

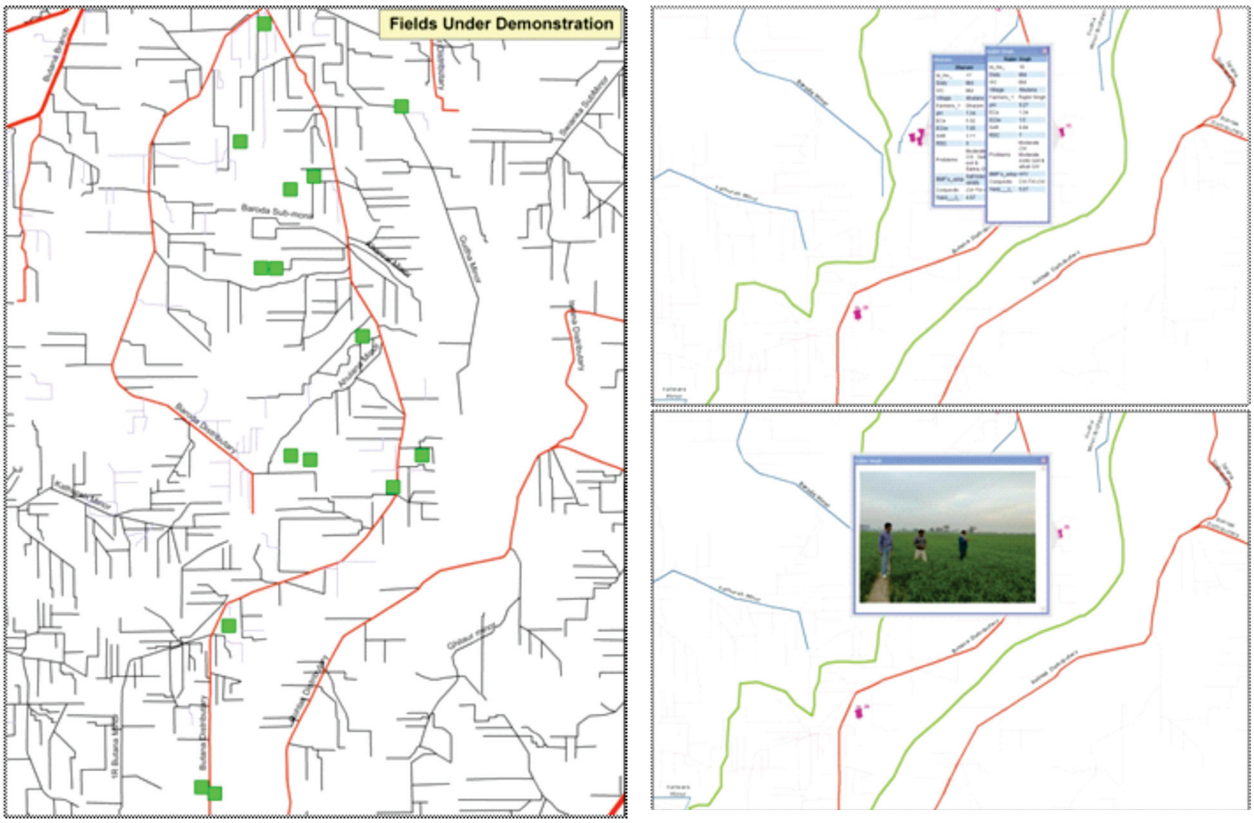


Fig. 40. Field demonstration sites and database of different watercourses under Butana distributary

Fig. 41. Field demonstrations of wheat crop at Khanpur Khurd and Butana villages

➢ Transfer of DSS Knowledge to Stakeholders

Since stakeholder's servicing was the most important activity of the project with 13% budget allocation, 121 district officers/engineers against the target of 30 officers/engineers from Command Area Development Authority, Agriculture Department, Irrigation Department, KVKs and Regional Research Stations of CCS Haryana Agricultural University, Hisar, and NGOs from 12 districts within the WYC Command in Haryana were imparted knowledge on DSS program and its application through 6 hands-on trainings and workshops for generating BMPs for enhancing productivity in saline environments (Fig. 42 and 43, and Annexure-II). Similarly, 1194 members from canal water users' associations and farmers against the target of 1000 farmers and WUA members from 8 districts (Karnal, Panipat, Sonipat, Jind, Rohtak, Jhajjar, Rewari and Bhiwani) were imparted knowledge on DSS generated BMP interventions through 13 trainings, field days, and workshops for growing bumper crop yield under deficit water supply, use of marginal and poor quality ground water, varying soil salinity and water logging, and poor soil fertility conditions (Fig. 44). The officers were quite keen to learn new tools for their application and even CADA has suggested funding more hands-on trainings on DSS application.

Fig. 42. Officers' capacity building and enhancement trainings on use of database and DSS program for enhancing productivity

Fig. 43. Project Partners' Meetings held at CSSRI, Karnal and NIH, Roorkee under chairmanship of DDG (NRM), Dr. A.K. Singh, DDG (NRM), ICAR and Dr. R.D. Singh, Director, NIH

Fig. 44. WUA members and farmers' capacity building and enhancement trainings organized at Butana, Baghpur and Ahulana villages

➢ Upscaling of DSS program

A feasibility assessment for upscaling of DSS program in 7 KVKs in terms of availability of computer hardware and software, internet connectivity, manpower, and power supply with generator backup was conducted at Panipat, Sonipat, Rohtak, Jhajjar, Rewari, Jind, and Kaithal. The problems observed were non-availability of suitable manpower (Agronomy/Soils/S&W Engg/Extension) at Rohtak, and irregular power supply during working hours at Panipat, Sonipat, and Jind due to the rural power supply connection. The DSS program was tested at existing computers at 3 KVKs (Panipat, Rohtak and Rewari) and the application was running perfectly fine and the backstopping services are also being provided. Six CADA Divisional offices at Karnal, Sonipat, Panipat, Rohtak, Jind and Kaithal were also assessed and have met all the requirements for software deployment. Since the theme area of the sub-project falls within the mandate of the institute, its upscaling will be continued from the Institute fund under 12th Plan. The user feedback on DSS program has been quite encouraging.

Project Website

A project website was updated regularly for publishing project information over web (Fig. 45) and can be accessed from a URL link (www.cssri.talents.co.in) for dissemination of project information including achievements, publication, project in press/media, meetings, upcoming trainings and workshops to the stakeholders, etc. The online database and online DSS program are made available from the project website for use by interested departments and users.

Fig. 45. Screen captured window of the project website

6. Innovations

A number of innovations were generated from this sub-project as follows:

- *An Irri-agro Informatics Geodatabase* of the WYC command was developed using the state-of-the-art geo-information technology by integrating 14 key thematic maps and data, and the existing databases acquired at free of cost or price from state line departments and central organizations. The database was updated with the current remotely sensed imageries and primary data. The *Geodatabase* has characterized bio-physical resources at the command, district, tehsil, village, distributary, and watercourse scale for rainfall distribution, adequacy of canal supplies, groundwater quality, saline/sodic soils, soil texture and, village information based on spatial querying for identifying water and land resource constraints for crop production. This geodatabase, distributed to 24 state line department officers who have license of ArcGIS software, has helped in identifying the resource constraints for optimising crop yield.
- The geodatabase of the WYC command was migrated to an open source GIS database (Quantum GIS version 1.7.4) for free distribution to the stakeholders along with GIS software for visualization and spatial querying, and producing value added maps. It is distributed to 61 CDs to state line departments and KVKs.
- To expand 24x7 use by stakeholders, the geodatabase was migrated to an open source geospatial server (GeoServer v2.3.0 software) which has published and disseminated the database online through web map service with leading geoportals in background for visualization and spatial querying to display the results over Google map/earth for identification of crop production constraints at watercourse or village level. The online database is made accessible from the project website.
- An user friendly DSS program for enhancing productivity in irrigated saline environment was developed using advanced programming language (C#) on .NET to evaluate different resource scenarios at farm level, predict the crop yield loss and recommend the BMP based interventions for crop productivity enhancement in six saline environments. The DSS modules were validated from the results of field demonstrations. The modules developed in different programming languages (Java, C# , etc.) were integrated which predict the yield loss with in the reasonable accuracy.
- The protocol for calibration and validation of SWAP and AquaCrop models using the experiment generated data was developed for wheat and maize crops under both deficit and irrigated saline regimes for complex scenario modelling.
- Stakeholder's servicing was given top most priority in the project to transfer the Database, DSS program and knowledge. 121 district officers/engineers from state line departments and KVKs were given adequate knowledge and skills on use of Database and DSS program through customise and hands-on trainings. Similarly, 1194 members from canal WUA and farmers from the WYC command were imparted knowledge on DSS generated BMP based interventions which were also demonstrated at farmers' fields for harvesting bumper crop yield in saline environments and the innovative demonstrations have won the trust of farmers for faster adoption.
- An online DSS was developed to meet the requirement of the stakeholders and state line departments which have the problem of regular transfer of district officers. The online DSS has expanded the usability of the program amongst officers. The Hindi versions of DSS program

and crop-water-salinity-yield response module were redeveloped and are popular among the stakeholders as well as in state line departments.

- A protocol for deciding the canal water delivery schedule for rostering in the command area was developed based on crop water demand using geospatial tools and CROPWAT model.

7. Process/ Product/Technology Developed

(List partner-wise major Process/ Product/Technology developed and their outcome in quantifiable terms)

S. No.	(Process/Product/Technology Developed	Adoption/ Validation/ Commercialization, etc.	Responsible Partner
1	Standalone *Irri-agro* Informatics Geodatabase of Western Yamuna Canal Command	Distributed to 66 Agriculture Department & CADA & KVKs, HR	CSSRI, WTC, NIH
2	GIS Methodology for identification and delineation of area of low productivity	Distributed to 8 Divisional Office of Agriculture Department and KVKs	CSSRI
3	Online visualization and spatial querying of the database for identifying crop production constraints at village level	Available online	CSSRI, WTC, NIH
4	Standalone DSS program for enhancing productivity in the WYC command	Distributed to 61 CADA & KVKs, Agri Dep, Haryana	CSSRI WTC, NIH
5	Crop-water-salinity-yield response model for predicting crop yield loss	Distributed to 40 Agriculture Dept, CADA and KVKs	CSSRI & WTC
6	Online DSS for irrigation scheduling with poor quality water for enhancing yield	Validated and available online	CSSRI
7	Demonstration of DSS generated BMPs at farmers' fields for enhancing productivity in irrigated saline conditions	52 farmers' fields	CSSRI & WTC
8	Calibrated and validated AquaCrop and SWAP for DSS	Adipted and integrated to DSS	WTC
9	Independent DSS module for deficit irrigation and with AquaCrop and SWAP integration	Validated and distributed to KVKs	WTC

8. Patents (Filed/Granted)

S. No.	Title of Patent	Inventor(s) (Name & Address)	Filed/Published/ Granted (No./Date)	Responsible Partner
1	N. A.	N. A.	N. A.	N. A.

9. Linkages and Collaborations

S. No.	Linkages developed (Name & Address of Organization)	Period (From-To)	Responsible Partner
1	IIRS, Dehradun	August 2009 to March 2012	CSSRI
2	NBSSLUP, Nagpur	August 2009 to March 2014	CSSRI
3	CGWB, Chandigarh	August 2009 to March 2013	CSSRI
4	HARSAC, Hisar	August 2009 to March 2013	CSSRI
5	CCS HAU, Hisar	August 2009 to March 2013	CSSRI
6	Agriculture Department, Panchkula	August 2009 to March 2014	CSSRI
7	Haryana Irrigation Department	August 2009 to March 2014	CSSRI
8	Command Area Development Authority, Haryana	August 2009 to March 2014	CSSRI
9	KVKs in 12 districts of WYC Command	August 2009 to March 2014	CSSRI
10	Haryana Operation Pilot Project (HOPP), Karnal	August 2009 to March 2014	CSSRI
11	IWMI India, New Delhi	January 2012 to December 2013	CSSRI
12	ICRISAT, Patancheru, Hyderabad	October 2010 to March 2011	CSSRI
13	ICARDA, New Delhi	June 2013 to March 2014	CSSRI
14	Agriculture Department, Haryana	August 2010 to March 2013	WTC
15	Command Area Development Authority, Chandigarh	August 2010 to March 2014	WTC
16	KVKs, Haryana	August 2009 to March 2014	WTC
17	Central Ground Water Board, Chandigarh & New Delhi	April 2010 to March 2013	NIH
18	Central Water Commission, New Delhi	April 2010 to March 2013	NIH
19	Haryana Irrigation Department	April 2010 to March 2013	NIH

10. Status on Environmental and Social Safeguard Framework

(Please see the project website for clarity on the issue under the sub-project)

The environmental and social safe guard frame work were considered exclusively in the sub-project as follows:

- Area under salt-affected lands and waterlogging has been decreasing due to adoption of efficient on-farm water and salinity management and drainage technology and awareness among farmers.
- Crop yield and income of farmers increased by growing good crops in saline soils/with saline water and waterlogging conditions.

11. Constraints, if any, and Remedial Measures Taken

- Leaving of project staff at regular interval slows down progress and achievements of the sub-project

- Regular shifting/transfer of district level officers/engineers puts hurdle on dissemination and usability of database and DSS program in state line departments/agencies.

Remedial Measures Taken

More candidates for project staff were put on the selection panel list. As the project staff leaves, the next available candidate on the panel list is asked to join within the short period in order to make continuity in the project work. This approach has solved the problem to some extent.

Developing and deploying online database and DSS program has improved the accessibility for interested officers/stakeholders/progressive farmers. These database and DSS program can be accessed from the project website. Therefore, more emphasis is given on this aspect to minimize the loss due to transfer of state line department officers.

Hindi support to DSS program and crop-water-salinity-yield response module were redeveloped and has catered the pressing demand of canal water users' association members and progressive farmers as well as in state line departments to popularize its use.

12. Publications

A. Research papers in peer reviewed journals

S. No.	Authors, Title of the paper, Name of Journal, Year, Vol. & Page No.	NAAS Rating	Responsible Partner
1	Singh, Gurbachan, Bundela, D.S., Sethi, M., Lal, K. and Kamra, S.K. (2010). Remote sensing and GIS for appraisal of salt-affected soils in India. *Journal of Environmental Quality,* 39(1): 5-15.	7.7	CSSRI
2	Abedinpour, M., Sarangi, A., Rajput, T.B.S., Singh, Man, Pathak, H. and Ahmad, T. (2012). Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. *Agricultural Water Management,* 110 :55-6.	7.6	WTC
3	Sarangi, A., Chakraborty, S., Wadkar, S.K., and Kumar, A. (2012). Estimation of future irrigation requirement for sustainable yield of *Kharif* maize under changing climate, *Mausam*, under review	3.2	WTC
4	Abedinpour, M., Sarangi, A., Rajput, T.B.S., and Singh, Man. (2011) Nitrogen use efficiency and yield of maize under deficit irrigation. *Journal of Agricultural Engineering* (ISAE): 48(4), 54-59	3.9	WTC
5	Lohani, AK, Kumar, R and Singh, RD. (2012). Hydrological time series modeling: A comparison between adaptive neuro-fuzzy, neural network and autoregressive techniques. *Journal of Hydrology*, 442–443 (6): 23–35.	7.8	NIH
6	Bundela, D.S., Sarangi, A., and Lohani, A.K. (2013). Assessing irrigation methods and scheduling strategies for enhancing productivity in Western Yamuna Canal Command in North-West India. *Under review in Agricultural Water Management.*	7.6	CSSRI

7	Bundela, D.S., Singhai, A. Sethi, M., Meena, R.L., Gupta, S.K., Tripathi, R.S., Kamboj, S., Sharma, P. and Saini, Pooja. (2013). Web based dissemination system of *Irri-agro* informatics spatial database of Western Yamuna canal command using open source software tools. Under review in *Indian Journal of Remote Sensing*, Dehradun	6.34	CSSRI
8	Abedinpour, M., Sarangi, A.(2013). Deficit Irrigation and Nitrogen Effects on Maize Growth in Semi Arid Environment, *World Applied Science Journal*, 21(11): 1687-1692	N.A.	WTC
9	Abedinpour, M., Sarangi, A., Rajput, T.B.S., Singh, M. (2014). Prediction of maize yield under future water availability scenariosusing the AquaCrop model, Journal of Agricultural Sciences, Cambridge (UK), doi:10.1017/S0021859614000094	8.88	WTC
10	Kumar, P., Sarangi, A., Singh, D.K. and Parihar, S.S. (2014). Evaluation of AquaCrop model in predicting wheat yield and water productivity under irrigated saline regimes, Irrigation and Drainage doi: 10.1002/ird.1841	7.42	WTC
11	Kumar, P., Sarangi, A., Singh, D.K. and Parihar, S.S. (2012). Water use efficiency of salt tolerant and non-tolerant wheat varieties under irrigated saline regimes, *Journal of Agricultural Engineering* (ISAE): 50 (1): 47-53	3.9	WTC
12	Kalra, B.S., Wadkar, S.K., Sarangi, A., Singh, D.K., Chaturvedi, A., and Singh, S.P. (2014). Farmers' perception on water management and land degradation in the tail reach of Western Yamuna Canal Command, *Journal of Rural Development*, (Under review)	3.09	WTC
13	Kumar, P., Sarangi, A., Singh, D.K., Parihar, S.S. and Sahoo, R.N. (2014). Modelling salt dynamics in the root zone and yield of wheat crop under irrigated saline regimes. *Agricultural Water Management* (Under Review AGWAT5776)	8.2	WTC
14	Kumar, P., Sarangi, A., Singh, D.K., Parihar, S.S. (2014). Wheat Performance as influenced by Saline Irrigation Regimes and Cultivars, *Journal of AgriSearch*, 1(2): 66-72	N.A.	WTC

B. Books/ Book chapters/ Abstracts/ Popular articles, Brochures, etc.

S. No.	Authors, Title of the papers/ Name of Book/ Seminar/ Proceedings/Journal, Publisher, Year, Page No.	Responsible Partner
1	Lohani, A.K., Kumar Rakesh, and Singh, R.D. (2009). Applications of soft computing techniques in hydrological modelling. In: Proc. International Conference on "Food Security and Environmental Sustainability (FSES-2009)", December 17-19, 2009, Kharagpur	NIH
2	Lohani, A.K., Kumar Rakesh, and Jain, S.K. (2009). Framework of decision support system for water resources planning and management. In: Proc. International Conference on "Food Security and Environmental Sustainability (FSES-2009)", December 17-19, 2009, Kharagpur	NIH

3	Lohani, A.K., Bashshitha, A. and Punia, A. (2009). Trend analysis of metreological data - A case study. In: Proc. National Symposium on Climate Change and Water Resources of India (CCWRIN), 18-19 November 2009, Organized by IAH, Roorkee	NIH
4	Bundela, D.S., Sethi, Madhurama and Meena, R.L. (2010). Remote sensing and GIS approach for delineation of areas of low productivity in the WYC Canal Command. Proc. *National Seminar on Soil Salinity and Water Quality, CSSRI, Karnal,* p 8	CSSRI
5	Kumar, P., Sarangi, A., Singh, D.K., Chakraborty, S., Wadkar, S.K. and Kumar, A. (2011). Soil salinity variation in the rootzone of wheat crop under irrigated saline environment. *In*: 45th ISAE Annual Convention and International Symposium on Water for Agriculture, Nagpur, 17-19 January, 2011. WFESI-8.23	WTC
6	Sarangi, A., Parihar, S.S., Singh, D.K., Rajput, T.B.S., Chakraborty, S., Wadkar, S.K. and Kumar, A. (2011). Comparative evaluation of crop coefficient of maize using weighing type lysimeter and FAO Penman-Monteith equation. *In*: 45th Annual Convention of ISAE and International Symposium on water for agriculture, Nagpur, 17-19 January, 2011, SWCAI-7.22, pp-138	WTC
7	Sarangi, A. and Sangwan, K. (2011). Delineation of salt-affected regions in Western Yamuna Canal Command using remote sensing and GIS. In: *32nd ISRS Annual convention and National Symposium on Empowering Rural India through Space Technology*, 9-11, November 2011, 137pp	WTC
8	Sarangi, A., Kumar, P. and Kumar, A. (2012). Yield responses of wheat to application of potassium under irrigated saline environment. In: *46th Annual Convention of ISAE and International Symposium on Grain Storage*, 27-29 Feb. 2012, Pantnagar, SWE-2012-SWCAI-7.15, 297pp	WTC
9	Proceedings of Regional Workshop on Groundwater Salinity: Assessment, Management and Mitigation, Karnal, 18-19 March 2011.	CSSRI
10	Bundela, D.S., Kumar, Sunil and Ram, Sita. (2011). Estimation of land surface temperature using Landsat-7 data and relationship between land use and land surface temperature, and normalized difference vegetation index. *Proceedings of XXXI INCA Annual Conference* held at Punjab University, Chandigarh during 15-17 October, 2011	CSSRI
11	Bundela, D.S., Hooda, R.S. and Rana, Mamta (2011). To map actual evaopotranspiration of wheat crop in a canal command using SEBAL model for assessing crop water demand. Proc. of the *National Symposium on ''Empowering Rural India through Space Technology"* Bhopal, 8 November 2011.	CSSRI
12	Abedinpour, M., Sarangi, A., Rajput, T.B.S. and Singh, Man. (2011). Evaluation of water use efficiency (WUE) and yield for maize under different nitrogen and water regimes. *21st ICID Congress and 62nd IEC Meeting*, October 15-23, Tehran, Iran	WTC
13	Gupta, S.K. and Bundela, D.S. (2011). Increasing agricultural productivity under saline environment in irrigation commands. Proc. of the *22nd Pacific Science Congress-2011*, 14-18 June 2011, Kuala Lumpur, Malaysia	CSSRI
14	Bundela, D.S. (2012). Problem based monitoring in irrigated command. Proc. of the *National Seminar on 'Modernization and Monitoring of Irrigated Commands'*, 21-22 November 2012, JNKVV, Jabalpur, p11-31	CSSRI

15	Lohani, A.K. and Goel, M. (2012). Applications of information technology in hydrological data analysis. In: *Role of Infrastructure for Sustainable Development*, Excel India Publishers, New Delhi, p663-672	NIH
16	डी.एस. बुंदेला, मधुरमा सेठी, आर.एल. मीणा, एस.के. गुप्ता, अनिल चिन्च्मलात्पुरे, आर.एस. त्रिपाठी, अकिंचन सिंघई, श्वेता कम्बोज, पूजा सैनी. (2013). सिंचित लवणीय वातावरण में फसल की उत्पादकता बढ़ाने हेतु निर्णय सहायक तन्त्र का निर्माण एवं अनुप्रयोग। सारांशः राष्ट्रीय संगोष्ठी– कृषि एवं पर्यावरणः अवसर व चुनौतियाँ, करनाल, 13–15 मार्च 2013	CSSRI
17	डी. एस. बुंदेला, अकिंचन सिंघई, श्वेता कपम्बोज, पूजा सैनी, मधुरमा सेठी, आर. एल. मीणा, एस.के. गुप्ता, अनिल चिन्च्मलात्पुरे, आर.एस. त्रिपाठी (2013). नहरी–कृषि संसूचनाओं के प्रसार हेतु भौगोलिक सूचना प्रणाली एवं इन्टरनेट आधारित सूचना तंत्र का निर्माण एवं उपयोगिता। सारांशः राष्ट्रीय संगोष्ठी– कृषि एवं पर्यावरणः अवसर व चुनौतियाँ, करनाल, 13–15 मार्च 2013	CSSRI
18	Sharma, D.K., Bundela, D.S., and Kamra, S.K. (2013). Strategies for improving water productivity in saline and waterlogged areas of Yamuna Basin. Proceedings of *Workshop on Enhancing Water Use Efficiency in Yamuna Basin* held on 30 August 2013 at NASC complex, New Delhi	CSSRI
19	Mondal, A.K., Sethi, Madhurama, Yaduvanshi, N.P.S., Yadav, R.K., Bundela, D.S., Chinchmalatpure, A.R. and Sharma, D.K. (2013). Salt-Affected Soils of Nain Experimental Farm: Site Characteristics, Reclaimability and Potential Use. Technical Bull. No. 03/2013. CSSRI, Karnal, p24	CSSRI

13. Media Products Developed/Disseminated

S. No.	CD, Bulletins, Brochures, etc. (Year wise)	No. of Copies	Distribution	Responsible Partner
1	Sarangi A. and Bundela, D.S. (2011). *Decision support systems in water resources management: A Review*. Technical Bulletin, TB- ICN: 88/2011, Water Technology Centre, IARI, New Delhi, 56p	40 copies	District officers of State line departments and KVKs	WTC & CSSRI
2	Sarangi, A. (2011). *Data acquisition and analysis using GPS and GIS: A User Manual*. NAIP:70-22/IARI/UM2-2011, Water Technology Centre, IARI, New Delhi, 20p	200	State line departments	WTC
3	Sethi, Madhurama, Khurana, M.L., Bhambri, Rakesh, Bundela, D.S., Gupta, S.K., Ram, Sita, Chinchmalatpure, A.R., Chaudhari, S.K. and Sharma, D.K. (2012). *Appraisal of salt-affected and waterlogged soils in Rohtak, Bhiwani, Jind and Jhajjar districts of Haryana using Remote Sensing and GIS*. Technical Bulletin no. 2012/02, Central Soil Salinity Research Institute, Karnal, India, p28	20	Agriculture department and KVKs	CSSRI

4	Project brochure in English and Hindi	800	State line department and stakeholders	CSSRI, WTC & NIH
5	Compendium on *'Applications of modern tools for enhancing productivity in irrigated saline environment'*. CD released during the training, 2011 and 2012	64	Senior officers of CADA, Agriculture and irrigation Departments and KVKs	CSSRI
6	*Online DSS for irrigation scheduling with poor quality groundwater*, 2011	40	participants of Capacity Building training	CSSRI
7	BMPs for *Enhancing productivity in irrigated saline environment*, brochure, 24-28, August 2011: 6p	50	For distribution to participants and interested faculties.	CSSRI
8	Updated project website (www.cssri.talents.co.in) Last updated on 31 March 2014	Online	For dissemination online to stakeholders	CSSRI, WTC & NIH

14. Meetings/Seminars/Trainings/*Kisan Mela*, etc. Organized

S. No.	Details of Meetings/Seminars/ Trainings, etc.	Duration (From-To)	No. of Personnel Trained	Organizer (Name & Address)
1	*Kharif Kisan Mela* held at Experimental Farm at Nain, Panipat district	15 October 2013	43	CSSRI, Karnal
2	Modern Tools in Water Management	19-23 Aug 2013	19	CSSRI, Karnal
3	*Rabi Kisan Mela* held at CSSRI, Karnal	1 March 2013	55	CSSRI, Karnal
4	DSS based management strategies for enhancing crop yield in canal commands	5-7 February 2013	22	CSSRI, Karnal
5	Innovation Day cum *Kharif Kisan Mela* held at Moi-Majri, Sonipat district	9 Oct 2012	80	CSSRI, Karnal
6	Workshop-cum-training for senior officers on '*Use of decision support tools for enhancing crop yield in irrigated saline environment*'	28 March 2012	21	CSSRI, Karnal
7	Officers training on *Water management strategies for enhancing crop yield in canal commands*	22-24 March 2012	20	CSSRI, Karnal
8	Farmers' Field Day held at Baghpur village (Jhajjar district)	15 March 2012	60	WTC, New Delhi
9	Farmers' Field Day held at Bhaisru Khurd village (Rohtak district)	14 March 2012	56	WTC, New Delhi

10	Farmers visit to Farm Technology demonstration in the *Rabi Kisan Mela* held at Karnal	1 March 2012	110	CSSRI, Karnal
11	Farmers' Field Day held at Ahulana village (Sonipat district)	24 February 2012	214	CSSRI, Karnal
12	Post-Demonstration Participatory Rural Appraisal (PRA) Meeting at Butana (Sonipat district)	21 Aug. 2011	70	CSSRI, Karnal
13	Project Partners' Meeting held at NIH, Roorkee	28-29 June 2011	18	NIH, Roorkee
14	Field Visit day-cum-*Rabi* Crop Appraisal Meeting	8 April 2011	92	CSSRI, Karnal
15	Capacity Building Training Programme for Farmers and WUA Members	3 and 5 March 2011	198	WTC, New Delhi
16	Senior Officers' Capacity Building Training '*Applications of Modern Tools for Enhancing Productivity in Irrigated Saline Environment*'	1-5 March 2011	20	CSSRI, Karnal
17	Stakeholders' Capacity Building Training	28 January 2011	165	CSSRI, Karnal
18	Project Partners' Meeting under chairmanship of DDG (NRM)	2 November 2011	12	CSSRI, Karnal
19	Capacity building workshop cum training on "*Use of Geospatial tools, Models and DSS in Enhancing productivity of Irrigated Saline Environment*"	24-28 Aug 2010	19	WTC, New Delhi
20	Project Partners and Staff Training *Performance Evaluation of Canal Irrigation Projects using Remote Sensing and GIS* at IIRS, Dehradun	15-24 April 2010	20	CSSRI, Karnal
21	Stakeholders' sensitization training for farmers and water user association members	31 March 10	94	CSSRI, Karnal

15. Participation in Conferences/ Meetings/Trainings/ Radio talks, etc.

S. No.	Details of Meetings/ Seminars/Trainings/ Radio talk, etc.(Name &Address)	Duration (From-To)	Budget (₹)	Participant (Name & Address)
1	Rashtriya Sangosthi on *Agriculture and Environment- Challenges and Opportunities* held at CSSRI, Karnal	13-14 March 2013	0.06	Dr. D.S. Bundela Akinchan Singhai Shweta Kamboj Pooja Saini, CSSRI, Karnal

2	National Seminar on *"Modernization and Monitoring of Irrigated Commands"* held at JNKVV, Jabalpur	*21-22 November, 2012*	0.5	Dr. D.S. Bundela CSSRI, Karnal
3	International Agronomy Congress, New Delhi.	November 26-30, 2012	0.07	Dr. A. Sarangi WTC-IARI, New Delhi
4	International Symposium on BIO-ENERGY- Challenges and Opportunities by ISAE, at Hyderabad	January 28-30, 2013	0.05	Dr. A. Sarangi WTC-IARI, New Delhi
5	Advance Soft Computing Techniques in Hydrology and its Applications (ASCTHA -2011), Roorkee	20–24 June, 2011	0.4	Dr. D.S. Bundela CSSRI, Karnal Dr. A.K. Lohani Mr Ajeet Singh Chhabra NIH, Roorkee
6	National Seminar on Management of Salt Affected Soils and Waters: Challenges of the 21st Century, Lucknow	16-17 March, 2012	0.12	Dr. D.S. Bundela Akinchan Singhai Sandeep Rastogi, CSSRI, Karnal
7	Pacific Science Congress 2011, Kuala Lumpur, Malaysia	14-18 June, 2011		Dr. S.K. Gupta, CSSRI, Karnal
8	XXXI INCA Annual Conference held at Punjab University, Chandigarh	15-17 October, 2011		Mr. Sunil Kumar CSSRI, Karnal
9	National Symposium on Empowering Rural India through Space Technology, Bhopal	6-11 November, 2011		Dr. A. Sarangi and Mr. Kamaldeep Sangwan WTC-IARI, New Delhi

16. Foreign Trainings/Visits

S. No.	Name, Designation, Address of the Person	Visit/Training/ Seminar its Place, Organization and Duration (From-To)	Dates of Seminar Delivered and Report Submitted on Return	Follow up Action	Total Cost (₹ lakhs)
1	Dr. A. Sarangi Senior Scientist WTC-IARI, New Delhi	Geospatial tools for integrated water resource management, Texas A&M University, College Station, USA, 22 March-12 April 2011	12th May 2011 and report submitted on 13th May 2011	Follow up action taken	2.13
2	Dr. S.K. Gupta, PC, CSSRI, Karnal	Pacific Science Congress 2011, Kuala Lumpur, Malaysia, 14-18 June 2011	18th June 2011 and report submitted	Follow up action initiated	1.41

3	Dr. D.S. Bundela Principal Scientist CSSRI, Karnal	GIS technology for canal database and DSS development, Texas A&M University, College Station, USA, 13 Sep-14 Oct 2011	14th November 2011 and report submitted on 29 Nov, 2011	Follow up action taken	2.84

17. Performance Indicators

Performance Indicators for Component-1: ICDS

S. No.	Indicator	Total No.
1	No. of hits on the sub-project website per month	497
2	Number of knowledge products developed: e-courses e-learning modules	N.A.
3	Digitization of number of: Ph. D. Theses Historical publications	N.A.
4	Enhanced knowledge sharing and public awareness activities carried out	12 (1194 WUA Members & farmers)
5	Development of linkages with National organisations International organisations	 13 3
6	No. of articles downloaded from CeRA subscribed publishers	N.A.
7	Training of critical mass (no. of experts trained)	121
8	Number of scientists trained overseas in the frontier areas of science	1
9	Number of scientists trained overseas in Consortia-based subject areas	2
10	No. of scientists participated in conference/seminar etc. abroad	1
11	Number of novel tools/protocols/methodologies developed	
12	**Publications**	
	Articles in NAAS rated journals	10
	Articles in other journals	6
	Book(s)	--
	Book chapter(s)	10
	Thesis	5
	Popular article(s) (English)	7
	Newspaper article(s)	10
	Seminar/Symposium/Conference/Workshop Proceedings	13
	Technical bulletin(s)	3
	Manual(s)	5
	CDs/Videos	6
	Popular article(s) in other language	1
	Folder/Leaflet/Handout	8
	Report(s)	3
	Success stories	4

18. Employment Generation (man-days/year)

S. No.	Type of Employment Generation	Employment Generation up to Mar 14	Responsible Partner
1	Contractual staff as RA, SRF and OA, daily paid persons at project level and farmer level for demonstration of BMPs	10316 man-days	CSSRI
2	Contractual staff as SRF, daily paid persons at project level and farmer level for demo of BMPs	5349 man-days	WTC
3	Contractual staff as RA, daily paid persons at project level	1718 man-days	NIH

19. Assets Generated

(Details to be given on equipment and works undertaken in the sub-project, costing more than ₹ 10,000/- in each case)

(i) Equipment

S. No.	Name of the Equipment with Manufacturers Name and Model	Year of Purchase	Quantity (Nos.)	Total cost (₹ lakhs)	Responsible Partner
CSSRI, Karnal					
1.	Mid end workstation with 20" TFT Monitor, DELL T5500 model	2009-10	One	2.14	CSSRI
2.	Online UPS, 2.0 KVA APC RT2000	2009-10	One	0.37	CSSRI
3.	GIS software, ESRI ArcGIS ArcInfo v9.3.1	2009-10	One	6.76	CSSRI
4.	Remote sensing software, ERDAS Imagine Professional v9.3, Leica	2009-10	One	3.07	CSSRI
5.	Wide Format Scanner, HP Scanjet N9120	2010-11	One	1.27	CSSRI
6.	Wide format plotter, HP Model T-1200	2009-10	One	3.05	CSSRI
7.	MS Visual Studio 2008	2010-11	One	0.38	CSSRI
8.	Satellite Data, Resourcesat LISS-3 & 4 from NRSC, Hyderabad	2009-10 & 2010-11	34 scenes	1.44	CSSRI
9.	OSM digital topo data,1:50k Survey of India, Dehradun	2010-11	22 tiles	3.63	CSSRI
10.	GPS enabled digital Camera, Panasonic model TZ10	2011-12	One	0.24	CSSRI
11.	Differential GPS system, Trimble GeoXT 2008 Series	2010-11	One	6.80	CSSRI
12.	Field Datalogger with ET, Soil moisture and Salinity, Water Flow Sensors-Dataker, Dynalab, Stevens, GlobeWater, Microsensor	2011-12	One	9.90	CSSRI

13.	Field EC & pH meter, Eutech Cyberscan Series PC300	2010-11	One	0.55	CSSRI
14.	Doppler Flow Meter, Fuzi Electric, Japan, FSC S10B1-0Y	2010-11	One	3.14	CSSRI
15.	Portable leaf area meter, CID Bio-Science, CI-202	2011-12	One	2.24	CSSRI
16.	Precision Balance, KERN, ABT220-5DM	2010-11	One	1.13	CSSRI
17.	Laptop, Dell Latitude 5500	2009-10	One	0.52	CSSRI
18.	Color laser printer, HP model CP2025n	2009-10	One	0.35	CSSRI
19.	Windows and Split 1.5T AC, Carrier, Durakool Plus & Estrella model	2010-11	Three	0.87	CSSRI
WTC-IARI, New Delhi					
1.	Mid end workstation with 2KVA UPS, DELL Model T5500 and Uniline UPS	2009-10	One	2.30783	WTC
2.	Arcinfo ArcGIS software (9.3), ESRI	2009-10	One	6.76	WTC
3.	Remote sensing software (ERDAS Imagine Prof v 9.3)	2009-10	One	2.26720	WTC
4.	MS Visual Studio & programming software (2008 Professional)	2009-10	One	0.31938	WTC
5.	Digital camera, Sony model Exmor DSC-TX7	2009-10	One	0.25110	WTC
6.	DGPS rover unit, Trimble GeoXT 2008 Series Geo explorer	2009-10	One	2.99775	WTC
7.	Field datalogger with 8 sensors and data retrieval system for deficit irrigate. Sentek sensor technology (Enviro Scan Solo)	2010-11	One	8.60183	WTC
a	Salinity meter (Saturation Extract Kit) HACH Model no-18700	2010-11	One	0.89046	WTC
b	Ground water depth monitoring system Hydrolab (Surveyor) Hach Environmental	2010-11	One	1.28730	WTC
c	Data retrieval system Sony Vaio VPCS123FG	2010-11	One	0.84375	WTC

8.	Colour laser printer, HP model CP2025	2009-10	One	0.3492	WTC
9.	A.C. charge for Voltas split and Carrier window (2 T)	2010-11	Three	0.89900	WTC
NIH, Roorkee					
1.	Mid end workstation, HP model Z600	2010-11	One	1.81	NIH
2.	20" TFT monitor, HP	2010-11	One	0.24828	NIH
3.	Remote sensing software ERDAS Imagine Prof V 9.3	2010-11	One	3.06800	NIH
4.	Digital Camera, Nikon Coolpix L-120	2011-12	One	0.18350	NIH
5.	Colour laser printer, HP/CLJ model CP2025	2010-11	One	0.34920	NIH

(ii) Works

S. No.	Particulars of the Work, Name and Address of Agency Awarded the Work	Year of Work Done	Quantity (Nos.)	Total Cost (₹ lakh)	Responsible Partner
1	Wall cover unit in NAIP Geoinformatics Lab and Office (M/s Chawla Furniture, Karnal)	2010-11	Two	0.39	CSSRI
2	Renovation of Lab	2010-11	One set	0.30	WTC

(iii) Revenue Generated

(Details may be given on revenue generated in the sub-project viz., sale of seeds, farm produce, products, patents, commercialization, training, etc.)

S. No.	Source of Revenue	Year	Total amount (₹)	Responsible Partner
1	N.A.	N.A.	N.A.	

(iv) Livestock

(Details of livestock procured/produced in the sub-project)

S. No.	Details of Livestock (Breed, etc.)	Year of Procurement/ Production	Nos.	Total Cost (₹)	Responsible Partner
1	N.A.	N.A.		N.A.	

20. Awards and Recognitions

S. No.	Name, Designation, Address of the Person	Award/ Recognition (with Date)	Institution/ Society Facilitating (Name & Address)	Responsible Partner
1	Dr. S.K. Gupta	Fellow award in 2013 Fellowship award, CSSRI Excellence award in 2011	ISAE, New Delhi ISCAR Society, Canning CSSRI, Karnal	CSSRI
2	Dr. D.S. Bundela	Selected as Principal Scientist in 2010 (Direct Selection)	ASRB, New Delhi	CSSRI
3	Mr. Akinchan Singhai	Young Scientist Award in 2012	MP COST, Bhopal	CSSRI
4	Dr. A. Sarangi	Shankar Memorial Award in 2012 Best Paper Award for the publication in S No5 during year 2013 Best paper award by ISAE for the publication in S no4 during year 2014 NAAS Associate in 2009	Indian Society of Agricultural Engineers (ISAE), New Delhi Indian Society of Agricultural Engineers (ISAE), New Delhi Indian Society of Agricultural Engineers (ISAE), New Delhi NAAS, New Delhi	WTC
5	Dr B.S. Kalra	CADWM award in 2010	Ministry of Water Resources, New Delhi	WTC
6	Dr. A.K. Lohani	Selected as Scientist-F in 2012	NIH, Minstry of Water Resources, New Delhi	NIH

21. Steps Undertaken for Post NAIP Sustainability

- Since the Database and DSS program have been demonstrated to state line departments and KVKs in Haryana, CADA has extended the funding support for organizing hands-on trainings for officers and demonstration of DSS generated BMP interventions at farmers' fields for their upscaling. This would help in full deployment of DSS program in the district offices and validation with user datasets.
- Since the theme area of sub-project falls within the mandate of the institute, its upscaling would be continued from the Institute fund under 12th Plan after the closure of funding support from NAIP. Therefore, project activities have been included in the Institute Research Programme under XIIth Plan for post-NAIP sustainability.
- Continued support and upgradation of database and DSS program are required to upscale the project result more acceptable and meaningful to stakeholders as it can be seen long term supports for DSS projects worldwide. A project proposal on deployment of DSS program in other canal commands will be submitted to DST for funding.

22. Possible Future Line of Work

- Upscaling of DSS application to larger stakeholders as well as to other similar canal commands is required to be undertaken.
- Impact assessment of DSS application and DSS generated BMPs based interventions at state stakeholders and farmers' level needs to be carried out in post NAIP project phase.
- Development of web DSS from a standalone DSS is required to be undertaken with bilingual support (Hindi) for its fast adoption and popularization.
- Since the user technical support and upgradation of DSS program is continuing process as can be seen worldwide in DSS projects, the continued support for new operating systems and user problems are required to be provided.

23. Personnel

(Staff of Lead Centre & Partner-wise, their Name, Designation, Discipline and Duration)

Staff	Period (From – To)
CSSRI, Karnal	
Research Management (CL)	
Dr. D.K Sharma, Director & Consortia Leader	28 October 2010 - 31 March 2014
Former CL	
Dr. S.K. Gupta, Acting Director & Consortia Leader	30 June 2010- 27 October 2010
Dr. Ram Ajore, Acting Director & Consortia Leader	15 January 2010- 30 June 2010
Dr. Gurbachan Singh, Director & Consortia Leader	May 2009 - 15 January 2010
Scientific (CPI, others)	
Dr. D.S. Bundela, Principal Scientist & CPI	May 2009 - 31 March 2014
Dr. S.K. Gupta, PC (SWS)/Emeritus Scientist & Co-PI	May 2009 - 31 March 2014
Dr. Madhurama Sethi, Principal Scientist & Co-PI	May 2009 - 31 March 2014
Dr. R.L. Meena, Senior Scientist & Co-PI	May 2009 - 31 March 2014
Dr. R.S. Tripathi, Principal Scientist & Co-PI	May 2009 - 31 March 2014
Dr. Anil R. Chinchmalatpure, Principal Scientist & Co-PI	August 2012 - 31 March 2014
Former Scientific	
Dr. N.P.S. Yaduvanshi, Principal Scientist & Co-PI	August 2009 - 31 July 2012
Technical Staff	
Er. S.K. Dahiya, T-5	6 February 2010-24 January 2013
Contractual Staff	
Dr. Akinchan Singhai, RA (RS & GIS)	2 December 2011 - 31 March 2014
Ms. Shweta Kamboj, RA (Programming)	30 December 2009 - 31 March 2014
Ms. Pooja Saini, OA (IT)	25 August 2009 - 31 March 2014
Er. Parmod Sharma, RA (SWCE)	30 July 2013 - 31 March 2014

Former Staff	
Dr. Ram Suresh, SRF (Agricultural Extension)	22 August 2010 - 15 January 2010
Dr. Mukesh Kumar, RA (Soil Science)	25 August 2009 - 24 August 2010
Mr. Sunil Kumar Jangra, RA (RS & GIS)	27 August 2009 - 30 Nov 2011
Mr. Anil Kumar, RA (Soil Science)	28 September 2010 - 19 January 2012
Mr. Sandeep Rastogi, SRF (Agricultural Extension)	27 September 2010 - 14 June 2012
WTC-IARI, New Delhi	
Research Management (CP)	
Dr. H.S. Gupta, Director & Consortia Partner	May 2009 - 31 March 2014
Scientific (CCPI, others)	
Dr. A. Sarangi, Principal Scientist & CCPI	May 2009 - 31 March 2014
Dr. D.K. Singh, Principal Scientist & Co-PI	May 2009 - 31 March 2014
Dr. B.S. Kalra, Principal Scientist & Co-PI	May 2009 - 31 March 2014
Technical Staff	
Mr. Ashok Kumar, Technical Officer	May 2009 - 31 March 2014
Contractual Staff	
Mr. Mohd Saqib, SRF (RS & GIS) Mr. Sudheer Kumar, SRF (SWCE)	17 July 2013 - 31 March 2014 23 July 2013 -31 March 2014
Former Staff	
Ms. Shiulee Chakraborty, SRF (SWCE)	September 2009 - December 2010
Mr. Sagar Wadkar Kisan, SRF (Agril Economics)	October 2009 - July 2011
Mr. Kamaldeep Sangwan, RA (RS & GIS)	June 2010 - August 2011
Mr. Mudit Kapoor, SRF (RS & GIS)	November 2011 - May 2012
Mr. Surendra Pratap Singh, SRF (SWCE)	April 2011 - July 2012
Mr. Anurag Chaturvedi, SRF (Agril. Extension)	October 2011 - 31 March 2013
NIH, Roorkee	
Research Management (CP)	
Dr. R.D. Singh, Director & Consortia Partner	May 2009 - 31 March 2013
Scientific (CCPI, others)	
Dr. A.K. Lohani, Scientist-F & CCPI	May 2009 - 31 March 2013
Dr. M.K. Goel, Scientist-F & Co-PI	March 2010 - 31 March 2013
Dr. N. Panigrahy, Scientist-C (WRDM) & Co-PI	May 2009 - 28 February 2010
Contractual Staff	
Mr. Ajit Singh Chhabra, RA (RS & GIS)	15 April 2010-31 December 2012

24. Governance, Management, Implementation and Coordination

A. Composition of the various committees (CIC, CAC, CMU, PMAC, etc.)

S. No.	Committee Name	Chairman (From-To)	Members (From-To)
1.	PMAC	Dr. S.L. Mehta, Chairman PMAC, 2009-11	Dr. Mahesh Uppal, Member PMAC, 2009-11

B. List of Meetings organized

S. No.	Details of the meeting	Date	Place & Address (Where meeting organized)
1	Project Monitoring and Advisory Committee (PMAC) Meeting chaired by Dr. S.L. Mehta & Dr. N.T. Yaduraju, NC (Conponent-1)	12 March 2010	CSSRI, Karnal
2	Project Partners' Meeting chaired by Dr. A.K. Singh, DDG (NRM), ICAR, New Delhi	2 November 2010	CSSRI, Karnal
3	Project Partners' Meeting chaired by Dr. R.D. Singh, Director, NIH, Roorkee	28-29 June 2011	NIH, Roorkee
4	Project Partners' and Staff Meeting	4 April 2012	WTC, New Delhi
5	Project Review Meeting by Director, CSSRI	17 June 2013	CSSRI, Karnal
6	Project Partners' and Staff Meeting	30 July 2013	WTC, New Delhi
6	Cross Cutting Workshop of ICT Sub-projects of NAIP	6-7 December 2013	NASC, New Delhi

Part-III: Budget and its Utilization

STATEMENT OF EXPENDITURE

***(Period from** May 2009 **to** 31 March 2014)*

Sanction Letter No. 30(51)/2009/Decision Support/NAIP/O&M, dated 12 May 2009 & 11 May 2012

Total Sub-project Cost: ₹ 305.55 lakhs

Sanctioned/Revised Sub-project cost *(if applicable)*: ₹ 317.7394/ 355.59740 lakhs

Date of Commencement of Sub-project: July 2009

Duration: 4 years and 9 months

Funds Received in each year:

I Year: **₹ 148.12**

II Year: **₹ 67.7093**

III Year: **₹ 10.18607**

IV Year: **₹ 23.7933**

V year: **₹ 14.23149**

Bank Interest received on fund *(if any)*: ₹ 1.32985 lakhs

Total amount received: **₹ 264.04016** lakhs

Total expenditure: **₹ 217.03576** lakhs

Expenditure head-wise:

Sanctioned Heads	Funds Allocated	Funds Released						Expenditure Incurred						Balance
		1st Year	2nd Year	3rd Year	4thYear	5th year	Total	1st Year	2nd Year	3rd Year	4thYear	5th year	Total	
A. Recurring Contingencies														
(1) TA	12.70	2.10	3.83735	-2.09092	1.10	0.42500	5.37143	0.43735	1.09308	0.48808	0.22903	0.43088	2.67842	2.69301
(2) Workshops	3.25	0.64	0.88	0.38	0.20	0.55500	2.65500	0.57281	0.19222	0.70	0.00000	0.00000	1.46503	1.18997
(3) Contractual Services/RA/SRF	68.448	9.31	20.9074	7.96568	11.956	7.84800	57.98708	5.73119	21.44068	21.33164	13.78071	11.80215	74.08637	-16.09929
(4)Operational Cost	49.40	6.16	19.596	1.64679	8.8005	4.30000	40.50329	5.73908	8.51192	7.73478	4.84609	4.89634	31.72821	8.77508
Sub-Total of A (1-4)	**133.798**	**18.21**	**45.22075**	**7.90155**	**22.0565**	**13.13300**	**106.52180**	**12.48043**	**31.2379**	**30.2545**	18.85583	17.12937	109.95803	-3.43623
B. HRD Component														
(5) National Training	28.12	5.04	3.08	0.00000	0.00000	0.00000	8.12000	3.26	6.28686	1.34914	0.00000	0.00000	10.89600	-2.77600

(6)International Trainings & Conferences	11.50	0.00000	6.27855	1.40906	0.00000	0.00000	7.68761	0.00000	3.50	2.00	0.00000	0.00000	5.50000	2.18761
(7) Consultancy	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Sub-Total of B (5-7)	**39.62**	**5.04**	**9.35855**	**1.40906**	0.00000	0.00000	**15.80761**	**3.26**	**9.78686**	**3.34914**	0.00000	**0.00000**	16.39600	-0.58839
C. Non-Recurring														
(8) Equipment	125.1	120.2	4.90	0.00000	0.00000	0.00000	125.10000	38.23218	28.20008	16.73347	0.00000	0.00000	83.16573	41.93427
(9) Furniture	1.40	1.40	0.00000	0.00000	0.00000	0.00000	1.40000	0.97414	0.00000	0.00000	0.00000	0.00000	0.97414	0.42586
(10) Works (new renovation)	7.00	1.00	6.00	0.00000	0.00000	0.00000	7.00000	0.1485	0.1531	0.40	0.00000	0.00000	0.70160	6.29840
(11) Others (Books, etc.)	1.10	0.90	0.20	0.00000	0.00000	0.00000	1.10000	0.11798	0.2121	0.00000	0.00000	0.00000	0.33008	0.76992
Sub-Total of C (8-11)	**134.6**	**123.5**	**11.1**	0.00000	0.00000	0.00000	134.60000	**39.4728**	**28.56528**	**16.73347**	0.00000	0.00000	84.77155	49.82845
D. Institutional Charges*	9.7214	1.37	2.03	0.87546	1.7368	1.09850	7.11076	0.17	2.03246	1.84247	1.80662	1.43735	7.28890	-0.17814
Grand Total (A+B+C+D)	**317.7394**	**148.12**	**67.7093**	**10.18607**	**23.7933**	**14.23149**	**264.04016**	**55.38323**	**70.24378**	**52.17958**	**20.66245**	**18.56672**	**217.03576**	**47.00440**

* Institutional charges will be 10% of the recurring contingencies for the Lead Consortia and 5% for Consortia Partners.

(Note: ₹ 50.63138 lakhs of balance fund for 2011-12 including interest earned were returned to PIU-NAIP, New Delhi on 31 March 2012 to ensure zero balance in the sub-project account at CSSRI, WTC and NIH)

(D.S. Bundela)
Name & Signature of CPI :
Dated: 20/02/2014

(Ved Parkash)
Name & Signature of Competent Financial authority:
Dated: 20/02/2014

(Dr. D.K. Sharma)
Director, CSSRI, Karnal
Signature, name and designation of Consortia Leader

Dated: 24/02/2014

PART-IV: DECLARATION

This is to certify that the final report of the sub-project has been submitted in full consultation with the Consortia partners in accordance with the approved objectives and technical programme and the relevant records, note books; materials are available for the same.

Place: Karnal

Dated: 17 February 2014

(D.S. Bundela)
Signature of Consortia Principal Investigator

(A. Sarangi)
Consortia Co-Principal Investigator
WTC, IARI, New Delhi
Dated: 15 February 2014

(A.K. Lohani)
Consortia Co-Principal Investigator
NIH, Roorkee
Dated: 15/02/2014

Date: 24 March 2014

(Dr. D.K. Sharma)
Signature of Consortia Leader & Director
CSSRI, Karnal

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Annexure-I

Table A.1. Canal water allowances & irrigation depth in selected distributaries in WYC system

Distributary	Water Allowance at outlet (cusecs/ 1000 acres)	Irrigation Depth (mm) at different years/ canal irrigation intensity (*Rabi*)				
		Planned	2001-02	2006-07	2016-17	Farmers
		25%	35%	39%	55%	100%
Butana	3.01	51.5	36.8	33.0	23.4	12.9
Gangesar	2.86	49.0	35.0	31.4	22.3	12.2
Kahanaur and Jhajjar distributary	2.40	41.1	29.3	26.3	18.7	10.3

Table A.2. Four groups rotational programme for running of channels of WYC system for *rabi* 2013-14

Period		Group Preference Order			
From	To	I	II	III	IV
27.10.2013	03.11.2013	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri
04.11.2013	11.11.2013	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa
12.11.2013	19.11.2013	Bhalaut+ SIRSA	JLN+Habri	Butana+NLS	Sunder+Markanda
20.11.2013	27.11.2013	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS
28.11.2013	05.12.2013	Butana+NLS	Sunder+Markanda	Bhalaut+ SIRSA	JLN+Habri
06.12.2013	13.12.2013	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa
14.12.2013	21.12.2013	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS	Sunder+Markanda
22.12.2013	29.12.2013	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS
30.12.2012	06.01.2014	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri
07.01.2014	14.01.2014	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa
15.01.2014	22.01.2014	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS	Sunder+Markanda
23.01.2014	30.01.2014	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS
31.01.2014	07.02.2014	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri
08.02.2014	15.02.2014	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa
16.02.2014	23.02.2014	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS	Sunder+Markanda
24.02.2014	03.03.2014	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS
04.03.2014	11.03.2014	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri
12.03.2014	19.03.2014	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa
20.03.2014	27.03.2014	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS	Sunder+Markanda
28.03.2014	04.04.2014	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri	Butana+NLS
05.04.2014	12.04.2014	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa	JLN+Habri
13.04.2014	20.04.2014	JLN+Habri	Butana+NLS	Sunder+Markanda	Bhalaut+ Sirsa

Note: NLS stands for Naggal Lift Scheme; JLN stands for Jawahar Lal Nehru Group; Habri stands for Habri Group; Markanda stands for Markanda Group; and Sirsa stands for Sirsa Group

Table A.3. Wheat yield under BMP demonstration at farmers fields in Butana distributary

Field ID	Location		Village	Soil Quality		G.W Quality			Problems	BMPs adopted	Yield, t ha^{-1} (Increase, %)
	Disty	WC		pHs	ECe	ECiw	SAR	RSC			
1	Head	Tail	Jagsi	7.60	1.92	1.70	7.61	2.95	Deficit CW, Normal soil, and Marginally alkali GW	Salt tolerant variety (KRL-210) Laser leveling & gypsum bed, Irrigation Scheduling	5.87 (22%)
2	Head	Mid	Jagsi	7.85	6.06	4.18	6.14	0.00	Moderate CW, Saline soil & Saline GW	Salt tolerant variety (KRL-19) Conjunctive use	5.32 (17%)
3	Head	Tail	Jagsi	8.32	1.46	2.57	7.80	1.25	Deficit CW, Slight sodic soil, Marginally saline GW	Salt tolerant variety (KRL-210) Conjunctive use	5.85 (18)
4	Head	Mid	Gangana	9.13	3.40	2.87	8.76	2.50	Moderate CW, Moderate sodic soil & marginally alkali GW	HYV (HD-2894), Conjunctive use	3.80 (20%)
5	Head	Tail	Gangana	8.77	3.84	3.34	10.26	0.00	Deficit CW, Slight sodic soil & Marginally saline GW	HYV (HD-2851), Conjunctive use	3.37 (17%)
6	Head	Tail	Bichpuri	9.48	1.55	1.43	13.85	6.73	Deficit CW, Moderate sodic soil & Highly alkali GW	Salt tolerant variety (KRL-210), gypsum bed, Irrigation Scheduling	6.82 (28%)
7	Head	Tail	Bichpuri	9.03	2.09	2.43	11.23	5.25	Deficit CW, Moderate sodic soil & Highly alkali GW	Salt tolerant variety (KRL-210) , Laser leveling, gypsum bed, Irrigation Scheduling	6.67 (31%)

8	Head	Tail	Bichpuri	7.93	2.51	1.95	10.17	7.47	Deficit CW, Normal soil & Highly alkali GW	Salt tolerant variety (KRL-210), gypsum bed, Irrigation Scheduling	5.75 (27%)
9	Mid	Mid	Butana	8.59	1.08	0.43	6.01	0.00	Moderate CW, slight sodic soil & good GW	HYV (HD-2851) laser leveling, irrigation scheduling	5.17 (24%)
10	Mid	Mid	Butana	7.21	5.56	4.40	3.18	0.00	Moderate CW, saline soil & saline GW	Salt tolerant variety (KRL-210), conjunctive use	5.67 (21%)
11	Mid	Tail	Butana	8.13	1.38	5.18	10.26	0.00	Deficit CW, normal soil & saline GW	HYV (HD-2851), UGPL, conjunctive use	5.82 (32%)
12	Mid	Tail	Butana	8.00	6.02	7.05	13.73	0.00	Deficit CW, saline soil & saline GW	Salt tolerant variety (KRL-210), UGPL, conjunctive use	6.40 (33%)
13	Mid	Mid	K.Khurd	8.25	2.84	3.25	11.57	0.00	Moderate CW, slight sodic soil &marginally saline GW	HYV (HD-2894), conjunctive use	5.90 (26%)
14	Mid	Tail	K.Khurd	8.32	3.43	5.36	13.39	0.00	Deficit CW, slight sodic soil & high SAR saline GW	Salt tolerant variety (KRL-210) conjunctive use	5.65 (23%)
15	Mid	Mid	Ahulana	9.27	1.34	1.50	9.86	7.00	Moderate CW, moderate sodic soil & alkali GW	HYV (HD-2894), irrigation scheduling with gypsum	5.07 (19%)
16	Mid	Tail	Ahulana	7.99	5.68	7.07	2.69	0.00	Deficit CW, saline soil & saline GW	Salt tolerant variety (KRL-210), conjunctive use	5.60 (27%)
17	Mid	Mid	Ahulana	7.34	5.02	7.05	3.11	0.00	Moderate CW, saline soil & saline GW	Salt tolerant variety (KRL-210), conjunctive use	4.67 (20%)
18	Mid	Head	Ahulana	7.84	7.40	7.21	3.90	0.00	Deficit CW, saline soil & saline GW	Salt tolerant variety (KRL-19), conjunctive use	2.90 (19%)

19	Tail	Tail	Chhichrana	8.84	1.25	4.70	16.59	0.00	Moderate CW, slight sodic soil & saline GW	Salt tolerant variety (KRL-210), conjunctive use	4.62 (28%)
20	Tail	Tail	Chhichrana	8.00	4.90	1.30	10.26	0.00	Moderate CW, saline soil & highly alkali GW	HYV (DBW-17) laser leveling, Irrigation scheduling	5.32 (30%)
21	Tail	Tail	Chhichrana	8.00	5.10	1.30	9.90	0.75	Moderate CW, saline soil & good GW	HYV (DBW-17), laser leveling, irrigation scheduling	5.02 (27%)
22	Tail	Tail	Sanghi	7.81	1.65	3.13	13.87	6.25	Deficit CW, normal soil & highly alkali GW	HYV (HD-2894), zero tillage, gypsum bed, conjunctive use	4.75 (21%)
23	Tail	Head	Sanghi	9.06	1.50	1.55	9.24	5.75	Moderate CW, moderate sodic soil & alkali GW	HYV (DBW-17), zero tillage, gypsum bed, irrigation scheduling	4.70 (22%)
24	Tail	Tail	Sanghi	9.08	1.55	1.83	13.39	0.00	Deficit CW, moderate sodic soil & highly alkali GW	HYV (HD-2894), irrigation scheduling	4.87 (26%)

Disty: Distributary Canal; WC: Watercourse Channel; CW: Canal Water; GW: Groundwater; HYV: High Yielding Variety; UGPL: Under Ground Pipe Line

Annexure-II

Project events in press/media

Haryana Plus — Chandigarh, Friday August 28

Project for enhancing farm productivity on cards

TRIBUNE NEWS SERVICE

KARNAL, AUGUST 27

The launch of a project under the National Agriculture Innovation Project (NAIP) of the Indian Council of Agricultural Research (ICAR) on "Decision Support System for Enhancing Productivity in Irrigated Saline Environment using Remote Sensing, Modelling and GIS" is on the anvil.

The Rs 306-lakh project, to be implemented over a period of three years, is an extension of the component-1 of the NAIP for three years. It aims at developing a GIS-based decision support system (DSS) for the Western Yamuna Canal in the state by integrating bio-physical resources and socio-economic data to delineate the areas of low productivity and generate realistic best management practices for enhancing productivity.

The focus of the programme would be on areas under irrigated saline environment, including deficit canal water supply, poor soil and water quality and waterlogging conditions. The stakeholders would have access to computer programmes on DSS for effective trainings, field demonstrations and interactive workshops.

Giving details of the project at its launch workshop, Dr Mruthyunjaya, national director, NAIP, stressed the need for making science relevant for the welfare of society with focus on poor sections.

"The socio-economic sense of science must be persuaded during the implementation of the project and the importance of adopting a multi-disciplinary approach for carrying out such a project, focusing on profitability and livelihood security should be clearly explained," he emphasised.

Dr Ram Ajore, acting director, CSSRI said the technologies had been generated at the CSSRI for the reclamation of salt-affected soils and these would be included in the decision support system to be developed under the project.

Dr NT Yaduraju, national coordinator, NAIP, informed that 24 such projects were sanctioned under the component-I of the NAIP and highlighted the importance of the sanctioned projects.

Underlining the importance of information, communication and dissemination system (ICDS) as a thrust area in the component-I, he said research and developing new techniques was incomplete unless stakeholder servicing to infuse confidence in the stakeholders.

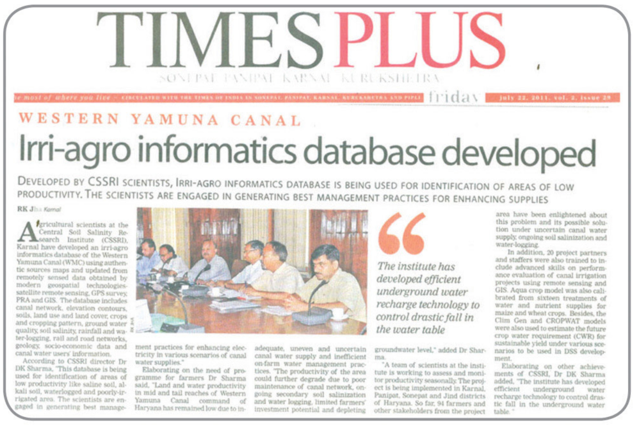
Dr DS Bundela, consortium principal investigator, the project was in consortium mode for utilising expertises of three participating institutions with unique inbuilt features of problem modelling and stakeholder servicing to infuse confidence in the stakeholders.

A project brochure in Hindi and English has also been prepared to give the details of the project to stakeholders in easy and lucid manner. As many as 52 delegates, including project partners and associates from Water Technology Centre, New Delhi, National Institute of Hydrology, Roorkee, and officers from the state line departments, participated in the workshop.

कृषि भास्कर — दैनिक भास्कर 14

प्रोजेक्ट | वैज्ञानिक कर रहे हैं खास प्रोजेक्ट पर काम, किसानों को मिलेंगी भूमि संबंधी जानकारियां

रिमोट सेंसिंग से जानो जमीनी हकीकत



TIMES PLUS

SONEPAT PANIPAT KARNAL KURUKSHETRA

WESTERN YAMUNA CANAL

Irri-agro informatics database developed

DEVELOPED BY CSSRI SCIENTISTS, IRRI-AGRO INFORMATICS DATABASE IS BEING USED FOR IDENTIFICATION OF AREAS OF LOW PRODUCTIVITY. THE SCIENTISTS ARE ENGAGED IN GENERATING BEST MANAGEMENT PRACTICES FOR ENHANCING SUPPLIES

"The institute has developed efficient underground water recharge technology to control drastic fall in the water table"

आज समाज

उत्पादकता बढ़ाने के लिए तकनीकों की दी जानकारी

आधुनिक तकनीक से बढ़ेगी गुणवत्ता

दैनिक भास्कर करनाल — पानीपत, रविवार 6 मार्च 2011

प्रशिक्षण परियोजना का मुख्य हिस्सा : बुंदेला

करनाल | सीएसएसआरआई में आयोजित प्रशिक्षण कार्यक्रम में भाग लेते वैज्ञानिक।

करनाल | केंद्रीय मृदा लवणता अनुसंधान संस्थान में सिंचित लवणीय क्षेत्र में उत्पादकता बढ़ाने के लिए आधुनिक तकनीकों का उपयोग विषय पर पांच दिवसीय प्रशिक्षण कार्यक्रम का शनिवार को समापन हुआ। डा. डीएस बुंदेला ने कहा कि ऐसे प्रशिक्षण कार्यक्रम परियोजना के अंतर्गत राज्य सरकार के अधिकारियों के लिए भी आयोजित किए जाएंगे।

उन्होंने कहा कि डेटाबेस तैयार कर कम उत्पादकता वाले क्षेत्र की पहचान कर ली गई है। इस क्षेत्र के लिए समुचित प्रबंधन रणनीति बनाकर 10 प्रक्षेत्र प्रदर्शन भी बुटाना नहरी क्षेत्र में लगाए गए हैं। उन्होंने परियोजना के उद्देश्यों पर प्रकाश डालते हुए कहा कि यह प्रशिक्षण परियोजना का एक मुख्य हिस्सा है। मुख्य अतिथि डा. डीके शर्मा ने कहा कि लवण ग्रस्त मृदा एवं जल का आधुनिक तकनीकियों द्वारा सटीक एवं उपयोगी डेटाबेस तैयार करने की दिशा में कार्य किया जाए। राज्य सरकार के संबंधित विभागों के साथ मिलकर जल एवं मृदा प्रबंधन की रूप रेखा तैयार की जाए। यही नीति निर्णय सहायक तंत्र के विकास में उपयोगी सिद्ध होगी। प्रशिक्षण के एक प्रतिभागी द्वारा संरक्षित खेती एवं लांग टर्म प्रयोगों पर बल दिया गया।

दैनिक भास्कर — पानीपत, शनिवार, 24 अगस्त, 2013

जल प्रबंधन की आधुनिक विधियां अपनाई जाएंः शर्मा

सीएसएसआरआई में 5 दिवसीय प्रशिक्षण का हुआ समापन

भास्कर न्यूज | करनाल

केंद्रीय मृदा लवणता अनुसंधान संस्थान जल प्रबंधन एवं फसल उत्पादन के आकलन हेतु जीपीएस एवं जीआईएस आधारित आधुनिक विधियों के उपयोग पर 5 दिवसीय प्रशिक्षण का विधिवत समापन संस्थान निदेशक डा. दिनेश कुमार शर्मा की अध्यक्षता में हुआ। समापन समारोह में सम्मानित अतिथि कार्यकारी अभियंता नहरी क्षेत्र पीके लूथरा रहे।

डा. डीएस बुंदेला, प्रशिक्षण निदेशक ने प्रशिक्षण की रूपरेखा के बारे में कहा कि आईटी, आईसीटी, जीपीएस, जीआईएस, डीएसएस का जल प्रबंधन के प्रयोग में कैसे लाया जा सकता है, पर अध्ययन करवाया गया। इस प्रशिक्षण के दौरान जल प्रबंधन में नहरी क्षेत्र विकास प्राधिकरण में क्या- क्या समस्याएं आ रही है, उनका कैसे निदान किया जा सकता है इन सभी बातों पर भी विचार -विमर्श किया गया।

डा. दिनेश कुमार शर्मा ने अपने अध्यक्षीय भाषण में कहा कि ऐसे प्रशिक्षणों में हिन्दी भाषा का प्रयोग आवश्यक है। ऐसे प्रशिक्षणों में दोबारा से उन्हीं प्रशिक्षणार्थियों का भाग लेना अति आवश्यक है। ताकि उन्हें ये सभी आधुनिक विधियां को दोबारा से दोहराया जा सके। सम्मानित अतिथि ने कहा कि जल एक बहुत बहुमूल्य संसाधन है। वैज्ञानिकों ने इसके समुचित उपयोग के लिए आधुनिक विधियां विकसित की है। उनका उपयोग में लाना एक महत्वपूर्ण कदम होगा। मंच संचालन संस्थान के प्रधान वैज्ञानिक एवं प्रशिक्षण निदेशक डा. डीएस बुंदेला द्वारा किया गया।

भाकृअनुप
ICAR

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