1 – INTRODUCTION TO INNOVATION TOOLS AND MANAGEMENT PRACTICES FOR SUSTAINABLE IRRIGATED AGRICULTURE IN CENTRAL ASIA

L. S. Pereira[1]

Abstract: After more than four years of cooperative research in the framework of the EU-INCO CIRMAN-ARAL project, a good number of achievements become available consisting of management tools and practices to improve irrigation aimed at in the Aral Sea Basin and in the Central Asia countries. This chapter intends to present the main tools and management practices developed for irrigation and drainage in a region under threat of water scarcity, desertification, salinization, limited economic resources, population growth, and submitted to the pressure of transition from a centralized to a market economy. Tools and practices refer to information technologies such as knowledge bas systems, database systems and remote sensing applications, mathematical simulation models and decision support systems.

Keywords: Aral Sea Basin, Fergana Valley, Information systems, Models, DSS, Irrigation and drainage, Desertification, Environmental impacts.

Introduction

The project "Crop irrigation management for combating desertification in the Aral Sea Basin", funded by the EU-INCO Copernicus program of the 5th Framework Program of the European Union initiated by 2000 and concluded 2005. A great deal of research has been performed in cooperation among four Central Asia institutions and two European ones. It resulted a good number of achievements that are aimed to contribute to the sustainability of irrigated agriculture in the region and to combat desertification induced by excess water use, salts concentration in the return flows, land salinization and other negative impacts of inappropriate water use in the area.

The project proved that there are management tools and practices able to stop and invert the negative on-going processes, and that may positively support

[1] Project Coordinator, Agricultural Engineering Research Center, Institute of Agronomy, Technical University of Lisbon, Tapada da Ajuda, 1349-017 Lisbon, Portugal. Email: lspereira@isa.utl.pt

new farming and water management practices leading to sustained yields, hopefully to increase land and water productivity and farmers incomes, as well as to help developing innovative water management practices at canal and upper levels.

The project shows that combining the existing with innovation knowledge it is possible to create new tools, so bringing research in the Central Asia institutions to the information technologies, IT era, based on a consistent and coherent scientific and technological knowledge as it is the case for the Central Asia research institutions. The political and economic changes largely affected their research potential but the knowledge potential continues to be a solid base for future developments and, in particular, for further implementing the research findings and tools created through this project. It is therefore important to present this volume, where each chapter shows a particular approach to respond to the challenges of future developments, as outlined in Chapter 2.

Research objectives

Irrigation in the Aral Sea basin, produced quite contradictory effects. On the one hand, it provided conditions to produce food and fiber crops, thus creating employment and incomes to the rural agricultural population, as well as to urban and periurban population working in the agro and textile industry. On the other hand, irrigation has caused very low flows in the rivers flowing to the Aral Sea, a built up of salinity in some cultivated soils where drainage is not effectively implemented, and an increase of salinity in the rivers when acting as collectors of the drainage water. In other words, irrigation has been successful in providing conditions for development in the semi-arid areas of Central Asia, but negative environmental impacts of irrigation are leading to physical desertification, i.e., in the long term, to permanent imbalance of water availability due to mining of water resources and degradation of water quality, combined with damaged soil, mainly due to salinity, with deterioration of the carrying capacity of the ecosystems and the degradation of the Aral Sea (Fig. 1), a formerly large fresh water lake that is now shrank and saline.

Many actions have been undertaken by national and international organizations to fight against this man-made desertification and to improve the economic, social and environmental conditions in this area. Main actions relative to the agricultural sector focused on drainage and salinity control, as well as on the operation and management of large irrigation systems. This project mainly focused the improvement of irrigation at the farm level because the effectiveness of field drainage, the volume of drainage flows and the amount of salts added to the downstream water depend on the way how irrigation water application is controlled at farm, while the improvement of water management of conveyance and distribution systems and the reduction of water resources mobilized for irrigation highly depend upon the farm demand. Coherently, the project also included studies on drainage and salinity control and issues on delivery schedules and practice aimed at matching the farm demand/irrigation schedules.

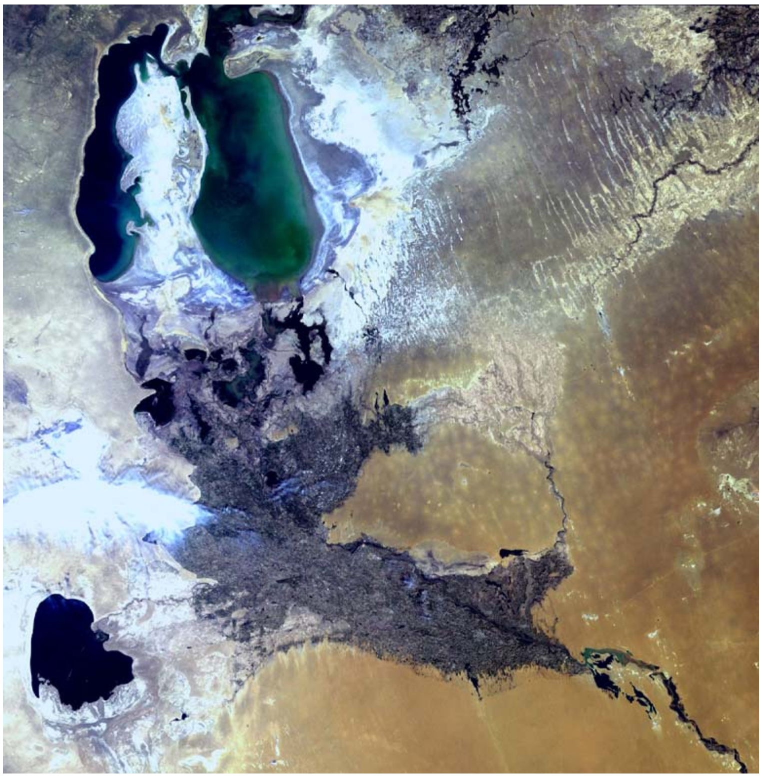

Fig.1. The Aral Sea by 2003.

Improving crop irrigation management has the potential to provide for reduced irrigation demand, smaller fraction of water added to the saline water table, higher effectiveness of salt control in the root zone, and higher yields per unit of water applied. Thus, improved crop irrigation management shall contribute to fight against desertification and to make it sustainable the irrigated agricultural in this water stressed region. In particular, it provides tools and practices that are essential to implement new issues on Integrated Water Resources Management (IWRM), particularly at level of Water User Associations (WUA), which is a main trend in the region (see chapters 2 and 20).

In this project the main focus is the Fergana Valley, in the upper part of the SyrDarya River basin, and interesting various regions of Uzbekistan, Kyrgyzstan, and Tajikistan (Fig. 2).

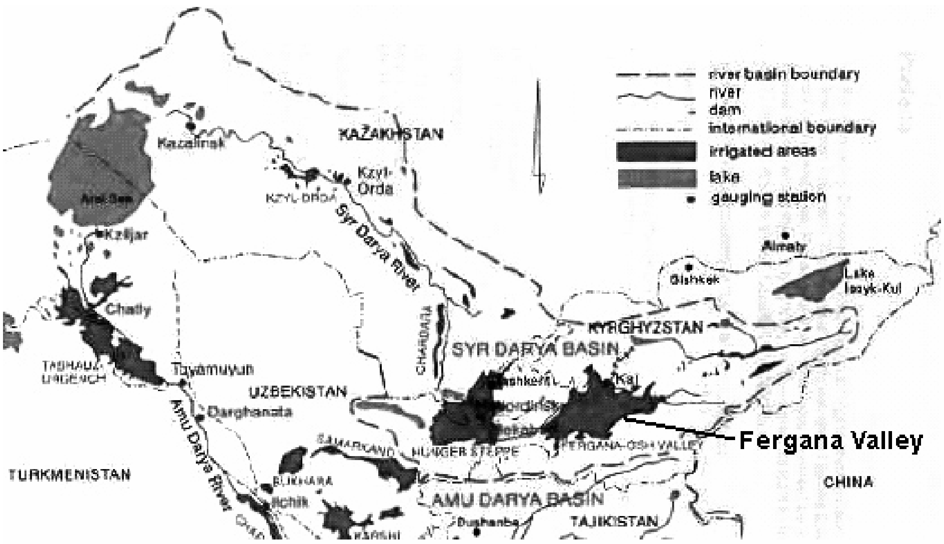

Fig. 2. The Aral Sea basin and the Fergana Valley in the upper Syr Darya basin.

The specific scientific and technologic objectives of this project were:

- To develop adequate tools to select the most appropriate reduced demand strategies for irrigation of main crops in the region, namely using crop-water-simulation models after field validation;
- To evaluate the technical, environmental and economic performances of field irrigation practices, and develop management and engineering solutions leading to minimize the percolation and runoff non-beneficial fractions of the applied water;
- To assess the drainage performance for control of salinity in irrigated agriculture, including the development of methodologies for the combined evaluation of drainage and irrigation, and practices for improving the soil and water quality;
- To identify main interface tools between farm and delivery systems, which could lead to reduce both system and on farm demand and water wastes and losses;
- To develop a knowledge base, database and geographical information systems to support the use of research tools and further application of project deliverables;
- To develop comprehensive decision support tools, comprising the validated simulation and analysis models, which could help system managers, farm advisers and farm decision-makers to select the most appropriate irrigation strategies to fight against desertification, i.e., that lead to water saving, salinity control and higher farmers incomes;

- To contribute with the scientific background for other environmental and development projects in the region, inclusive the dissemination of knowledge on rational water use, water conservation, and salinity control.

Information systems

A great deal of information has already been accumulated in Central Asian countries concerning virtually all issues pertinent to water management and water use, irrigated agriculture and desertification issues. Thus the creation of a knowledge base reflecting the Central Asian research made in the past and concerning the project major themes, namely irrigation, drainage, salinity, desertification and impacts caused by irrigation should be of great utility to scientists, experts, ecologists, policy makers and society as a whole. The Knowledge-Base system, accessible through a special window in the SIC ICWC website, is described in detail in Chapter 3.

The adoption of Information Technologies (IT) to prepare and elaborate the necessary databases for project implementation and modelling has been a main activity. Main attention was devoted to the development of GIS tools to make use of geo-referenced spatial data in modelling, and to explore the potential of remote sensing (RS) both to further support management and to create and update appropriate spatial data to be used with models operating with GIS tools. Thus an information system/database including GIS has been developed for Fergana to support implementing IWRM in Fergana Valley. It constitutes a prime achievement for further implementation of project findings and is described in Chapter 4.

The respective databases may be updated using remote sensed data (see Chapter 5) and allow to further use of models tested in the project.

Remote sensing

Remote sensing developments concern the following (Chapter 5):

- Land use classification by using of multi-temporal (10-day period) SPOT Vegetation NDVI profiles;
- Analysis of the 10-day SPOT Vegetation NDVI values relative to different area units (irrigation zones, administrative districts, collective farms) for 1999 to 2002;
- Classification of the main crops (cotton, winter wheat, maize) on the basis of average NDVI values for each parcel from two Landsat-7 ETM+ images of 2001;
- Soil salinity recognition through the analysis of the heterogeneity of NDVI values with help of a heterogeneity index purposefully developed;

- Estimation of crop coefficients (Kc) for winter wheat relative to 10-day periods derived from the NDVI values.

Two aspects call for special mention: the identification of salinity affected areas and the derivation of crop coefficients. In fact, the currently known salinity identification methods using RS do not apply satisfactorily to Fergana Valley because vast salt affected areas are not present in the region. Thus, a new methodology has been developed and results are promising, but require further research development to become operational. Relative to obtaining crop coefficients (Kc) from RS, a combined use of SPOT Vegetation and Landsat-7 ETM images allowed to adapt the existing methodology of deriving crop coefficients from a linear regression to NDVI when adopting the FAO56 methodology. It was possible to assess 10-day values for cotton and winter wheat Kc, which results are compatible with those in literatures and from experimentation (Chapter 7). RS derived Kc data may be implemented in the GIS database to be used in GISAREG.

Results from RS are easily incorporated in the georeferenced database of the Fergana region mentioned above, which show great potentialities for RS applications in irrigation management.

Irrigation requirements and scheduling. Crop-water-simulation models

Activities refer to several facets of implementing the updated technologies relative to: (a) crop water and irrigation requirements, which were validated relative to the methodologies currently adopted in the region; (b) testing and parameterizing irrigation scheduling and water management models; and (b) the installation of simulation models.

The first approach has been to provide for adopting the updated FAO56 guidelines (1998) relative to compute the reference ET (ETo) using the FAO Penman-Monteith method, and adopting the crop coefficients approach. Therefore, the comparison between ETo and ETp data was performed for several locations (Chapter 7).

The model WINISAREG has been successfully adopted aiming at computing crop water and irrigation requirements and irrigation scheduling. The model is described in Chapter 6. It has good capabilities for validation and, mainly, for using simulation options referring to a variety of modes to select irrigation depths and timings, to simulate deficit irrigation, to consider restrictions in water availability, and to estimate the groundwater contribution and percolation. Field experiments for irrigation scheduling and validation of the irrigation scheduling simulation models were set up at farms in Fergana, Uzbekistan, Karasu, Kyrgystan, and Khojent, Tajikistan, as described in Chapter 7. In addition to the referred experiments in Fergana Valley, the calibration and validation of the model were performed using field observations for cotton in the Hunger Steppe over the period 1982-1987, which included soil water and ET data, the later obtained through the energy balance method (Chapter 7). Model testing was successfully achieved, thus it may be considered that the model is installed and ready to be progressively implemented. Results led to set crop coefficients (Kc) and soil water depletion fractions for no stress (p) for cotton and winter wheat adapted to the regions under study, as well as to generate alternative irrigation schedules for the cotton and winter wheat crops in the Fergana Valley for full and deficit irrigation under conditions of maximal use of rainfall and control of percolation (Chapter 7).

The model has been explored for a variety of irrigation strategies aimed at water saving and percolation control as well as to limit the impacts of salinity on the irrigated soils, as analysed in detail in Chapter 8, including when adopting deficit irrigation schedule with assessment of respective impacts on yields. The implementation of WINISAREG for practical scheduling has been tested in several farms (Chapter 8). The model is run prior to planting and the planned schedule is proposed to the farmer; then the model runs at intervals of about one month with updated weather and irrigation data to improve estimations along the crop season. However, farmers tend to apply water in excess relative to the proposed "norms" and, quite often, apply more irrigations than planned. Extension/training is required.

Parallel to the development of the WINISAREG version of the model ISAREG, it was created GISAREG, which consists of the integration of ISAREG with the GIS ArcView 3.2, as described in Chapter 6. The great advantage of GISAREG is the use of spatial data from the developed GIS databases referred above (Chapter 4), including the use of remote sensed derived crop coefficients (Chapter 5), thus updated in real time when the respective methodology will become fully tested and operational.

The Root Zone Water Quality Model (RZWQM) was calibrated and used as a crop management tool. The calibration was conducted in an experimental field located in Azizbek farm, Fergana, on a Sierozem soil cropped with maize. The soil hydraulic properties were determined using an *in situ* monolith experiment together with laboratory methods, thus upgrading the respective methodologies. An extensive survey and laboratorial analysis were performed for chemical characterization of the soil and parameterization of the chemical components of RZWQM. Soil moisture, soil water potential, salt regime, and plant development were monitored (Chapter 9). Unfortunately, the chemical characteristics of the soil did not allow the exploration of the model for salinity studies but since the model is operational this possibility may be explored in future.

After calibration, the RZWQM model was run as a management tool to predict the impact of different irrigation and fertilization practices upon crop yields (Chapter 10). Relative to N fertilizing, results show that the maize crop does not respond to fertilizing above 200 kg/ha, which may be considered as the upper limit for appropriate fertilizing. Relative to irrigation, results show that the actual schedules lead to about 10% reduced yields. RZWQM may be used for simulation of various agricultural management scenarios can be used for further agro-economical analysis and assessment in view of water productivity and economic profitability. In parallel to modelling, studies were developed at several time and space scales to assess the land and water productivity in the region (Chapter 12).

Farm irrigation systems: improved practices and modelling

Activities refer to (a) upgrading the furrow irrigation systems; (b) install the simulation model SIRMOD based on appropriate field data collection and analysis for its parameterization and use; and (c) create the base data required for the DSS model SADREG

Main field studies were carried out in the farm “Azizbek-1”, central Fergana Valley. First, several furrow irrigation options with continuous flow were evaluated focusing alternate vs. every furrow irrigation, furrow lengths, inflow discharges, infiltration conditions as influenced by furrow compaction, and slopes, as described in Chapter 13. Other studies are reported in Chapter 11. The methodology used for the evaluation of furrow irrigation was upgraded and measurements relative to land levelling conditions, furrow discharges, furrow cross-sections, advance and recession, hydraulics roughness and infiltration allowed accurate parameterization of the simulation model SIRMOD. Selected performance indicators were considered.

The best performances for long furrows were observed for alternate furrow irrigation, which has good potential for water savings relative to every-furrow irrigation. The efficiency may greatly improve when cut-off times are adjusted to soil moisture deficit at time of irrigation in relation to inflow rates, thus avoiding the current over-irrigation (Chapter 13).

At a second stage, surge flow and continuous flow techniques were compared when applying water to every furrow or to alternate furrows. Later, field studies allowed to compare cotton irrigation treatments on water productivity (WP) and water use performance (Chapter 14). Considerable water savings may be achieved when adopting surge flow and alternate-furrow irrigation, from 200 up to 390 mm for the total irrigation season of cotton (Chapter 14). Surge flow has demonstrated the ability to reduce both deep percolation and tail end runoff. Advantages of surging are particularly visible for the early season irrigations.

Surge flow on alternate furrows shows to be the best technique for water saving and increased water productivity. When compared with the traditional every-furrow irrigation with continuous flow, water use was reduced by 3890 m^3/ha (44%) with a decrease in yield of 380 kg/ha (11%), while the water productivity was 0.61 kg/m^3 against 0.38 kg/m^3 for the traditional one. Moreover, the consumed fraction of water used at field level was quite high, 0.85 (Chapter 14).

Drainage and salinity control

Drainage and salinity control in Central Asia are well revised in Chapter 15. Field trials were developed at the Azizbek farm, in combination with referred irrigation experiments and trials. Particular attention was paid to the artesian flow, which is characteristic of the region and constitutes a non-negligible component of the water and salts balance.

To determine the subsurface drainage term of the water balance, all subsurface drainage volumes, as well as salt concentration in waters, were measured. It was verified that water and salt processes in the farm stabilized with almost "zero" balance in terms of salt "income"- "outcome" (Chapters 15 and 16). However, water and salt balances are different from plot to plot. The collected data indicate that even in well-drained areas with continued drainage operation, leaching requirements should be met in saline lands so that to avoid salinity restoration.

The average annual drainage modulus was observed to be 2 to 2.5 times smaller than that at construction, 1962-1964. The drains discharge varies within a wide range, with a maximum during the growing season due to irrigation, and the minimum by the autumn-winter period. The artesian contribution is about 100 mm/yr.

The groundwater salinity stabilized at 3.0-3.8 g/l regarding toxic salts and at 0.06-0.1 g/l regarding chlorine, against the initial 5.8-10 g/l. The total salinity changes insignificantly along the year. Due to leaching and low irrigation and ground water salinity, salt restoration processes are not observed: in the root zone (Chapter 16).

Decision support tools

The development of decision support tools for helping decision makers and other professionals to select the irrigation management practices and techniques that lead to improved water saving and improved environmental and socio-economics impacts of irrigation was a main issue in this project.

One decision support tool simulates the functioning of conveyance and distribution systems and adopts an optimization algorithm to improve matching the farm or field demand. It has been tested for a sub-network of Fergana canal and compared with the present situation (Chapter 17). This water delivery and allocation model responds satisfactorily by reducing the volume of water delivered, improving the timing of deliveries, controlling the operational water losses, and improving flow stability and supply equity.

The DSS software SADREG is a tool for surface irrigation design and is linked with a GIS georeferenced database. It integrates data, design and simulation models, multi-criteria analysis and user knowledge. It allows generating and ranking alternative farm improvement scenarios according to the user criteria. The database concerns field sizes and topography, soil intake rates, soil water holding capacity, crop data, irrigation management data (created through interactive simulations with the WINISAREG model), and economic data. The surface irrigation models include a land levelling module, and the SIRMOD simulation model, which can be applied for furrow, basin and border irrigation design. The farm systems for furrows refer to continuous and surge-flow, to the use of earth or lined ditches, gated pipes or layflat tubes, and the adoption of manual or automatic valves. The user may consider field length adjustments to adopt the multi-tier practice and runoff water reuse as developed years ago in Fergana Valley. The evaluation analysis includes cost and benefit calculations, and the determination of attributes relative to environmental and economic impacts. The priorities used for ranking the scenarios are user defined. The model is described in Chapter 18, where main results are analysed.

SADREG allows a rational generation, evaluation, and ranking of design alternatives. Design alternatives are easily associated with attributes of technical, economic and environmental nature, which allows an appropriate dialog between the designer and the user; using multicriteria analysis for ranking and criteria weights defined by the designer and users provide for better matching with the decision maker objectives.

The DSS model SEDAM has two major components: the farm irrigation and the canal distribution system. It simulates the water demand and delivery at the sector level (area served by a branch canal and respective distributor canals) and aggregates the results to the district level. It operates with a GIS database in combination with the irrigation scheduling simulation model GISAREG and the farm DSS model SADREG. The model generates scenarios based on system management actions relative to the delivery and the farm irrigation system. Each scenario expresses a set of measures corresponding to a strategy of improvement planned at the sector level, which refer to the farm level - irrigation scheduling, land levelling, farm water distribution, inflow rate control - and to the delivery system level, such as upstream inflow rates, delivery rules and daytime delivery. The canal network delivery model uses a simplified volume balance approach and computations include the estimation of canal seepage and runoff, as well as the lag time before the steady state flow regime is established. Fields are clustered according the user and a rotational delivery scheme is considered. The SEDAM model includes a multicriteria analysis module to formulate and evaluate alternatives in respect to user-selected performance, economic and environmental criteria (Chapter 19).

Results for SEDAM application show that there is a large potential for solving the existing excessive water use problems when improvements in the distribution system management are coordinated with those of farm irrigation to control runoff and seepage and to adequate deliveries to the farm irrigation scheduling. The SEDAM model has the potential to become a valuable tool to support decision-making relative to both the farm and distribution irrigation systems. However, it requires the production of an appropriate database and the parameterization of models used. The GIS integration increases the model capability to access input spatial data and creates a user-friendly interface both to run the model and to view the results. Future developments include coupling it with the model for hydraulic simulation and deliveries planning referred in Chapter 17.

Technology implementation

The implementation of the CIRMAN-ARAL results, including the field-tested improved irrigation scheduling, improved irrigation and drainage practices, the introduction into practice of the decision support tools, and the training of managers/extension technicians and farmers are to be developed as presented in the Table 1 as foreseen by the Inter-State Commission, the SIC-ICWC.

The main propose is to implement the new developed technologies, namely the decision support tools, in the Water User Associations (WUA) and Water Management Organizations (WMO), and in other projects carried out in the region, as at present in Fergana with IWMI, and other projects supported by different donors. The foreseen activities may have significant impact on future development of Integrated Water Resources Management (IWRM) as outlined in Chapter 20.

Table 1. Technology implementation plan and main measures as outlined by SIC-ICWC.

Measures	Customer	Users	Cost (1000 €)	Timing
Elaborating a set of dynamic irrigation norms based on the WINISAREG and SADREG for Central Asia States	Ministries of water (water & agriculture) of 5 States	WMOs, WUAs, farmers	130	2005 - 2007
Transfer models for WUA and Consulting services				
a) for pilot project IWRM Fergana	Provincial agricultural institutions	WUA, farmers	120	2005 - 2007
b) for other area			1420	2006 - 2010
Achieving stability of water delivery and minimizing operational losses by improving and implementing Models Gams /SEDAM				
a) improvement and coupling of models	Ministries of water of 5 States	WMO, WUA	460	2005 - 2006
b) application method				2006 - 2007
c) user training				2006 - 2007
Upgrading drainage calculation method taking irrigation into account land heterogeneity		WMO, WUAs and others	130	2005 - 2007

Some of the expected results from this joint engineering innovation, and the integration of technical and managerial aspects of IWRM, may lead to:

- The transfer to WUAs and respective consultants of the irrigation models and tools (WINIISAREG, SIRMOD, DSS SADREG, and others) relative to field water use and irrigation as oriented to change the adopted irrigation norms to be adapted to climatic variations, local soil conditions and cropping practices;
- The minimization of operational water losses in supply and delivery systems caused by adopting an up-down approach and use of updated tools. The joint use of models Gams (Chapter 17) and DSS SEDAM (Chapter 19) must evolve into an operational package; however, further developments are required;
- Land and water productivity increase through appropriate agronomic practices, precise irrigation scheduling, timely water delivery to fields and high uniformity and performance of irrigation systems.