# SUSTAINABLE USE OF IRRIGATION WATER: THE CASE OF TURKEY[1]

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Abstract: The Southeastern Anatolia Project (GAP) in Turkey, within the basins of Euphrates and Tigris rivers, targets construction of 22 dams and 19 hydroelectric plants while irrigating 1.7 million ha of land at a cost of US$32 billion. Due to recent financial and political instability experienced in Turkey, in 2008, the plan is significantly revised by an Action Plan to include allocation of US$8 billion to open 800,000 ha of previously unirrigated land to irrigation by 2012. Due to the lack of appropriate incentives to conserve water in a sustainable manner, inefficient and excess irrigation by users in the GAP region have already resulted in significant environmental problems such as waterlogging and salinity. To maintain long-term sustainability of irrigation projects, decentralization of irrigation management in Turkey started in 1993. The decentralized and locally-managed Water User Associations (WUAs) are responsible for distribution of irrigation water within their boundaries. However, WUAs in GAP have already turned into economic and political institutions dominated by powerful elites, reflecting the feudal structure of the region. Informal power distribution, based for the most part on area and closeness to political parties, has also resulted in favoritism. The purpose of this paper is to assess the environmental sustainability of the GAP region, first, by considering the institutional aspects of irrigation associations and, second, by developing a new water-salt balance model for simulating potential soil salinization in the region due to expanded irrigation.

*Keywords: Institutions, Irrigation, Salinity, Simulation, Turkey, Water User Associations*

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## 1. INTRODUCTION

The Southeastern Anatolia Project (Güneydoğu Anadolu Projesi, GAP) covers 9 provinces (Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa and Şırnak) in Turkey. As of 2009, over 300,000 ha of land are being irrigated in the region; at the completion stage of the project, 1.7 million ha (out of almost 3.2 million ha available for cropping) will be irrigated (GAP, 2006; GAP, 2009). The project is located on an area of 7.5 million ha within the upper-Euphrates (Fırat) and Tigris (Dicle) drainage basins. This land, corresponding to the watersheds of the lower Euphrates and Tigris rivers and the upper Mesopotamian plains, covers 20 percent of Turkey's irrigable area. The project area includes 3.1 million ha of cropland, 1.1 million ha of forest, and 2.4 million ha of rangeland and pasture (Ozdogan, 2006; Kibaroglu, 2003; FAO, 2001).

In the 1970s, GAP was planned to be a socio-economic project concentrating on development of infrastructure for irrigation services and provision of hydraulic energy production on the Euphrates and Tigris rivers. However, with the Master Plan announced in 1989 and the revision in 2002, the emphasis switched to a multi-sector development plan based on agriculture, industry, transportation, education, health, and rural and urban infrastructure (GAP, 2008; Ozhan, 2008). The project is also planned to generate employment for more than 3 million people (Kendirli et al., 2005).

Several incidents related to financial and political instability experienced in Turkey starting in the1980s and continuing into the 1990s led to a decrease in speed of realization of the initial GAP plan. The Kurdish question[3], in particular, was aggravated during these periods and was a key reason why the need for a revision emerged (Kirisci, 2007; Özhan, 2008). In May 2008, the prime minister of Turkey announced the *GAP Action Plan*. Besides the employment, education, and health dimension, the plan also includes the allocation of approximately US$8 billion to improve the irrigation infrastructure. Under the plan, in the coming five years (2008-2012), almost 800,000 hectares of previously unirrigated land will be opened to irrigation. The Action Plan targets achieving sustainable development in the region while concentrating on four themes: economic development, social development, development of infrastructure, and development of institutional capacity (GAP, 2008; Özhan, 2008).

Although the revised GAP program, in theory, emphasizes heavily the development of land and water resources, in application, environmental problems, such as salinity and waterlogging experienced in the region (described in detail below), result in environmental degradation. This brings into question the sustainable development aspects of the program (Dinçsoy, 2006).

The purpose of this paper is to assess the environmental sustainability of the GAP region, first, by considering the institutional aspects of irrigation associations and,

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[3] "Kurds are the dominant group in the GAP region relative to others. This area has long been plagued by confrontations between Kurdish separatists known as the PKK and the Turkish military that has proved very costly in terms of human life and economy" (Çarkoğlu and Eder, 2005, p.3).

second, by simulating potential soil salinization in the region due to expanded irrigation.

## 2. AGRICULTURE AND WATER RESOURCES IN TURKEY

### *2.1. Agriculture in Turkey*

Turkey, with a population of 74 million, has a GDP of around US$660 billion (current). Agriculture as a share of GDP is roughly 10%, and has historically employed between 25-30% of the workforce.

Turkey covers an area of 78 million ha with more than one third of it, about 28 million ha, being arable. The remaining area is mostly forests, pastures, meadows and open water bodies. Of the total arable land, 8.5 million ha is suitable for irrigation; mostly, seasonal and perennial crops are grown on these arable lands (FAO, 2001; Saysel, 2010).

The General Census of Agriculture for the year 2001 states that the total number of farms has not changed for the last 30 years. Small size farms (around 3 million), have a land share of 20 percent, middle-sized farms slightly more than 44 percent, and large size farms have a share of almost 35 percent. The size of average farm owned was under 5 ha both in 1970 and 1980 but has increased to 6 ha in 2001 (Ilkkaracan and Tunali, 2010). This figure in 2001 is roughly 2-3 ha in the northern and western regions; the corresponding value is larger in central and southeastern regions with 10 ha per household. The distribution of land cultivated in Turkey indicates that when small or peasant farmers are considered, two-thirds of farmers operate on land less than 5 ha and 18 percent on land between 5 and 10 ha (Saysel, 2010).

A wide range of agricultural products are grown in Turkey; these include the capital intensive export crops in western and southern Turkey and cereals in northern and northeastern Turkey. Still, cereals dominate agricultural policies in Turkey while exports mostly consist of both cereals and horticultural products (Aerni, 2007; Cakmak and Dudu, 2010; Saysel, 2010). Regarding area cultivated, share of field crops is more than 85 percent, orchards have a share of 10 percent, and vegetables around 3 percent. Almost 5 million ha is land left fallow (Cakmak and Dudu, 2010).

During the 1980-2005 period, the population growth in Turkey was 1.7 percent per year with the agricultural and non-agricultural output growing by 1.1 and 4.7 percent, respectively. Remarkably, the share of agricultural employment has fallen to under 25 percent for the first time at the end of 2008 (Ilkkaracan and Tunali, 2010). However, because the size of small farms has remained the same for the last few decades, combined with the agricultural sector performing worse than the rest of the economy, the income gap between rural and urban sectors has been widening. The end result is that the agricultural sector has the highest rate of poverty in Turkey (Karapinar, 2010). With low education rates and difficulties in finding off-farm employment, the rural sector is still facing an underemployment problem that results in social problems (Aerni, 2007; Aerni, 2010).

### *2.2. Water resources in Turkey*

The area feasible for irrigation in Turkey is 8.5 million ha consisting of 7.9 million ha from surface resources and 0.6 million ha from groundwater. As of 2007, 5.2 million ha are irrigated in Turkey with 94 percent of this area irrigated by surface methods, such as furrow or flood irrigation, and the rest by sprinkler and micro-irrigation. By 2023, the General Directorate of State Hydraulic Works (DSI) projections target irrigation of an additional area of 1.3 million ha (FAO, 2001; DSI, 2008).

Annual precipitation in Turkey in 2007 was 643 mm on average, amounting to 501 billion $m^3$ (BCM) per year (DSI, 2008). Total gross actual renewable water potential is calculated to be 234 BCM per year; however, considering technical and economic constraints, only 112 BCM (95 from domestic rivers, three from neighboring countries and 14 from groundwater) of this amount is estimated to be available for consumption. In 2007, per capita fresh water is calculated to be around 1,650 $m^3$ per year. However, by 2030, considering the 100 million population projection of the Turkish Statistical Institute, per capita fresh water will drop to the level of 1,120 $m^3$ per year (DSI, 2008). The Food and Agriculture Organization of the United Nations classifies Turkey as a country approaching the level of physical water scarcity.

Annually, over 50 million $m^3$ of water flows down the Euphrates and Tigris rivers and this represents 28% of Turkey’s water supplied by rivers. The GAP area has 22% of Turkey’s hydroelectric potential. The project targets construction of 22 dams and 19 hydroelectric plants. The initial cost of the project is calculated at US$32 billion (Ozdogan, 2006).

The arid GAP area comprises 10% of Turkey’s total area and holds 10% of its total population, but the GAP’s contribution to the GDP is only 5%. The relative underdevelopment of the region compared with other regions of Turkey is also underlined by government authorities and the plan emphasizes elimination of development disparities between the GAP and remaining regions of Turkey, while targeting economic growth and social stability (GAP, 2008).

### *2.3. The GAP region in detail*

#### *2.3.1. Crops planted: monoculture of cotton*

The soil structure and climate of the GAP region and the Harran Plain, in Şanlıurfa province that lies in the heart of the region, allow cultivation of cotton, maize, cereals, and vegetables. The original GAP master plan projected that around 25% of the area would be allocated to cotton. However, farmers started the monoculture cropping of cotton in the region due to convenience of accessing the tools and machinery for cotton farming, a stable price, ease of management and storage, and a secure market demand for the crop. The decision to plant cotton is also due to the strength of the textiles and clothing industries in Turkey that together have an export value of US$21 billion as of 2005. For example, during 2002 cotton was planted on 85% of land with the remaining 15% being allocate to cereals in Harran Plain. When only irrigated crops are considered, cotton’s share in the region rises to 96%. Currently, due to the juxtaposition of growing seasons of cotton and cereals in the region (cotton is planted in April and cereals harvested in May), farmers cannot plant both cotton and cereals within the same season. Cotton cultivation in the region occupies almost 90% of the area (DTM, 2005; Tekinel et al., 2002; ATO, 2005; Çullu, 2006; DSI, 2005; Kanber et al., 2005; GAP, 2004; Kün et al., 2005; Ozdogan, 2006).

### *2.3.2. Irrigation systems: sprinkler or drip instead of gravity and furrow—costs and benefits*

In 2007, water allocated for irrigation constituted 74% of all water used in Turkey. Irrigation in the GAP is being carried out mostly using open canals with gravity methods such as border and furrow irrigation; micro-irrigation is almost non-existent in the region. Against the monoculture of cotton, there is no effective policy regarding crop diversification.

Over 80% of irrigation in the region is provided by gravity or furrow methods (Adaman and Özertan, 2007). Research done in the region shows that even if micro-irrigation is the appropriate method for irrigation, farmers find it expensive to adopt and manage, especially for low to medium crop values such as the case of cotton. But for other high value crops such as tomato, farmers may find it appropriate to adopt drip irrigation (Luquet et al., 2005).

Technical solutions to overcome the negative externalities of excess irrigation, such as switching to closed pipe pressure systems and improving drainage facilities, are costly (UI, 2007); building pressure systems in the region cost around US$2,000/hectare—a significantly high amount considering that small-scale farmers operate on average on five hectares of land in Turkey. Use of electricity for pressured systems is expensive, whereas farmers benefit from gravity-based irrigation at minimal costs. In Harran, almost half of cropland is rented to sharecroppers and landholders who have rented out their land are impassive in the face of inefficient irrigation practices.

### *2.3.3. Pricing of water*

Currently, there are no water markets in Turkey and the pricing of irrigation water is area and crop based, thus, there is no incentive to use water in an efficient manner (Unver and Gupta, 2003). This leads to inefficiencies in irrigation applications where farmers sometimes apply even sevenfold of the required levels (Tekinel et al., 2002). When price increases are brought to the agenda, farmers claim that they already suffer from low productivity and constantly decreasing farm incomes (Ipek, 2005).

Governments in Turkey prefer to rely on engineering solutions to environmental problems rather than considering pricing as a tool to achieve efficiency. The end result is that sustainable use of resources is endangered; if all economically irrigated area in Turkey is developed, almost 18 basins in Turkey will experience water shortages (Çakmak et al., 2008).

## 3. ENVIRONMENTAL AND INSTITUTIONAL PROBLEMS FACED IN THE GAP REGION

### *3.1. Environmental problems*

Severe environmental problems faced in other countries, such as soil contamination from use of chemical fertilizers and deforestation are not much of problem for the Turkish agriculture. Nevertheless, since the policy makers in Turkey favored economic growth over its environmental consequences while designing agricultural policies, several environmental problems are being experienced in Turkey right now (Karapinar, 2010).

The GAP region, in general, and the Harran plain, in particular, have been showing signs in the last decade of having a salinity problem. Salinity was first observed in the region towards the end of 1970s during a time of irrigation done with only groundwater. Following the initiation of the GAP, water was brought to the region from the Atatürk Dam Reservoir, built on the Euphrates, through the Şanlıurfa irrigation tunnels in 1995. At that time, drainage systems were almost nonexistent in the region and so irrigation in the GAP started with no proper drainage (Adaman and Özertan, 2007).

Besides salinity, groundwater levels have also been rising over time. In the Harran Plain alone, it is estimated that, at the end of 2004, about 15,000 ha of land are strongly influenced by salinity and 40,000–50,000 ha are under the threat of a rising water table (Adaman and Özertan, 2007; Çullu, 2006). And, lastly, the soil erosion problem forms the third dimension of forthcoming infertility and aridity in the GAP region; unofficial estimates show that almost 450 tons of soils are eroded every day (Kün et al., 2005).

### *3.2. Institutional problems*

In Turkey, to maintain long-term sustainability of irrigation projects, decentralization of irrigation management started in 1993. The main reason for the management transfer process was the inability, or unwillingness, of the state agency to collect the irrigation fees in the presence of a hyperinflationary economy. Even the maintenance of existing irrigation systems could not be carried out in many cases due to lack of funds.

The decentralized and locally-managed Water User Associations (WUAs) were expected to increase efficiency, to promote sustainability of irrigation resources, and to establish horizontal networks among farmers. Especially, in regions where vertical tribal or kinship ties were present (such as parts of the GAP), the belief was that WUAs would provide the first experience with horizontal associations (Harris, 2005; Kudat and Bayram, 2000).

Today, the State Hydraulic Works (DSI) still maintains ownership of the infrastructure but the operation and maintenance of the secondary and tertiary canals have been transferred to WUAs. As of 2007, DSI has decentralized more than two million ha to water users in Turkey (DSI, 2008).

Decentralization of irrigation management serves two purposes: Sustainability of water resources is targeted by assuming that local management would emphasize sustainable use of water resources; and it provides opportunities for farmers to participate in the management of the associations. But, on the negative side, under absence of monitoring and oversight by the users and the state agencies and ministries, the WUAs can be under the threat of elite capture and are vulnerable to corruption and embezzlement of funds that are collected from the water users. Especially in regions where there are significant inequalities in the distribution of resources and power, WUAs are unable to ensure equitable distribution of water and fail to enforce irrigation fees equally—executive committee members and powerful farmers either evade fees or get significant reductions (Kadirbeyoglu, 2008; Kadirbeyoglu and Ozertan, 2010).

As opposed to the reasons behind decentralization, in a short time, WUAs in GAP turned into economic and political institutions dominated by powerful elites, reflecting the feudal structure of the region. Regarding productive efficiency, there is no indication that farmers use less water now that WUAs manage the irrigation scheme. The greatest impact has been an increase in the ability of WUAs to collect fees because farmers are dependent on them (Cakmak et al., 2004; Cakmak et al., 2007). Although it is one of the strategic decisions made by WUAs, that will also affect the institution’s sustainability, WUAs tend to set prices as low as possible while still allowing the associations to continue functioning, leaving no buffer fund to pay for serious repairs or maintenance.

Informal power distribution, based for the most part on area and closeness to political parties, has resulted in favoritism. Salaries to personnel hired are the major expenditure item on association budgets; allegations state that relatives of WUA chairmen are employed by several WUAs. Except for only a few cases, formal audits on financial statements are unlikely to take place, and, even if they are properly conducted, it is unlikely that the authorities would press for answers given the government’s predilection for avoiding conflicts with powerful regional leaders. Embezzlement and corruption arise even during the monitoring process of water use, presenting challenges to sustainability (Ul, 2007; Kıymaz, 2006; Şimşek et al., 2008).

WUAs lack the expertise or resources to invest in research and development and training programs to improve efficiency in water use and distribution. Availability of assistance to farmers regarding operating the irrigation systems and managing water resources is also limited (World Bank, 2007). In addition, WUAs cannot ensure equitable distribution of water nor enforce an equal irrigation fee schedule for all users–executive committee members and powerful farmers either refuse to pay fees for irrigation water used or receive significant reductions. In some regions, neighboring WUAs even compete for available water among themselves. The DSI prefers to avoid involvement in such problems.

## 4. IRRIGATION, SOIL SALINIZATION AND SIMULATIONS

In areas where precipitation is not sufficient for crops to grow, artificial irrigation is used as a means of supplementing soil moisture. The fraction of irrigation water that is ultimately available to crops is dependent upon the characteristics of the soil, and climatic factors. In many cases, irrigation allows farmers to create fertile agricultural land in arid and semi-arid regions, thereby stimulating their local economy with jobs and an increased crop yield. Globally, agricultural water use (in the form of crop irrigation) comprises 70% of all human water withdrawals with one of the main benefits being increased plant efficiency (Sahin et al., 2006) and hence, food production. However, there are environmental consequences that must be considered in order to assess the long-term economic benefits of irrigation. In order to maintain an effective and sustainable agricultural environment with artificial irrigation, a balance must be established between soil characteristics, the quantity and quality of applied water, and proper drainage. When any one or a combination of these factors is askew, environmental impacts such as soil salinization, waterlogging and rising groundwater levels can occur. These impacts are harmful to crop production and plant growth (Smedema, 1990), and can permanently degrade arable land.

Climatic factors such as the amount of sunlight, the intensity of sunlight, and temperature affect evaporation of water from the soil surface. This evaporative process depletes a soil's reservoir without serving the needs of the plants first. Salt is present in irrigation water and precipitation, and is also naturally occurring due to weathering of geological structures or sea water deposits. When water evaporates from the soil surface, it leaves behind the salt which continues to accumulate in the soil if there is not adequate water to flush it through the soil profile. Soil salinization occurs when the buildup of salts in a crop's root zone is significant enough that a loss in crop yield results (Houk et al., 2006). A buildup of salts in the soil makes it impossible for the roots of plants to take up water (Wright and Nebel, 2002) because salt accumulation increases the osmotic potential of the soil, reducing the plant's ability to extract water. Maas and Hoffman (1977) studied the relationship of salinization and crop yield and found that crops will generally be unaffected by an increase in salinity below a certain threshold. After this threshold is reached, the crop yield will begin to decrease as the concentration of salt in the soil continues to rise. This threshold and the response of different crops of increasing soil salinization varies greatly. Some crops, such as beans, are more sensitive to saline conditions than other crops, such as wheat, which are more tolerant (Houk et al., 2006).

While expanded irrigation can offer important beneficial effects on food production and local economies, it often results in environmental costs that are not considered in economic cost-benefit analyses or in the decision making process. For example, about 30 million hectares worldwide are severely affected by salinization (Kendirli et al., 2005). Szabolcs (1989) reported that more than 10 million hectares of irrigation fields are abandoned yearly because of salinization problems. As a first step in addressing this problem, we have developed a computer model which can be used to simulate and quantify two of the potential environmental costs of expanded irrigation in the GAP region: unsustainable water use and soil salinization. Both of these impacts potentially limit the economic benefits of the proposed doubling of irrigation in the GAP region. Model formulation and preliminary results are presented below. More comprehensive simulations of irrigation water demand and soil salinization impacts of current and expanded irrigation in the GAP region within the

Action Plan of 2008 are being conducted. The following sections can be considered as the first steps in developing a model for application to the GAP and the Action Plan of 2008.

### *4.1. SaltWBM: A water/salt balance model*

To simulate the potential environmental impacts of soil salinization due to irrigation, we used a water balance and salt balance approach. We coded the soil moisture balance equations from the Water Balance Model (WBM; Vörösmarty et al., 1998) in Microsoft Visual Basic for Applications (VBA) and added a drainage component and salt balance model, as described below.

#### *4.1.1. Soil moisture balance*

Soil moisture is controlled by soil moisture holding capacity and a drying function that is related to potential evapotranspiration. Following Vörösmarty et al. (1998), WBM's soil drying function relates soil moisture loss to potential evapotranspiration.

$$g(W_s) = \frac{1-\exp\left(-\alpha\left(\frac{W_s}{C}\right)\right)}{1-\exp(-\alpha)} \tag{1}$$

Here $W_s$ is soil moisture (mm), $\alpha$ is a constant set to 5 (Vörösmarty et al., 1998), and $C$ is soil moisture holding capacity that is related to soil-type and vegetation. The soil moisture deficit $D_{ws}$ (mm) can be defined as potential evapotranspiration $E_p$ (mm) plus the difference between soil moisture holding capacity $C$ (mm) and soil moisture $W_s$ (mm).

$$D_{ws} = C - W_s + E_p \tag{2}$$

We assume applied water $W_a$ (mm) is the sum of precipitation $P_r$ (mm) and irrigation $I_r$ (mm). If $W_a$ is less than $E_p$ then soil moisture, $W_s$, will decrease. Soil moisture $W_s$ in time-step $t$ is based on soil moisture in the previous time step ($t$ -1), modified by the drying function (eqn 1), and the difference between $E_p$ and $W_a$.

\#

$$W_{s,t} = W_{s,t-1} - g(W_{s,t-1})(E_{p,t} - W_{a,t}) \quad \text{for} \quad W_{a,t} \leq E_{p,t} \tag{3a}$$

If applied water is greater than potential evapotranspiration and less than the soil moisture deficit, then the soil moisture will increase

$$W_{s,t} = W_{s,t-1} + (W_{a,t} - E_{p,t}) \quad \text{for} \quad E_{p,t} < W_{a,t} < D_{ws,t-1} \tag{3b}$$

If the applied water is greater than the soil moisture deficit, then the soil is saturated and

$$W_{s,t} = C \quad \text{for} \quad W_{a,t} \geq D_{ws,t-1} \tag{3c}$$

When the soil becomes saturated, excess water is produced. The amount of excess water, $W_{x,t}$ is the difference between applied water and the soil moisture deficit at the previous time step

$$W_{x,t} = W_{a,t} - D_{ws,t-1} \tag{4}$$

*4.1.2. Infiltration and drainage*

In the WBM framework (Vörösmarty et al., 1998), infiltration into an unsaturated soil $I_{n(WBM)}$ (mm) is equal to applied water, when applied water is less than the soil moisture deficit

$$I_{n(WBM),t} = W_a \quad \text{for} \quad W_a < D_{ws,t-1} \tag{5a}$$

Alternately, infiltration is equal to the soil moisture deficit when applied water is in excess of the soil moisture deficit

$$I_{n(WBM),t} = D_{ws,t-1} \quad \text{for} \quad W_a \geq D_{ws,t-1} \tag{5b}$$

We added a saturated infiltration $I_s$ (mm) term. We assume that water can be infiltrated into a saturated soil at a rate of $f$ (mm/day), or simply a depth (mm) if the model is applied on a daily time step. Saturated infiltration allows water in excess of soil moisture deficit to percolate into the soil. Saturated infiltration is limited by either the saturated infiltration rate or by available excess water, $W_x$. In our modified version of WBM, infiltration is the sum of unsaturated infiltration and saturated infiltration. Saturated infiltration is $I_{s,t} = \min(f, W_{x,t})$ and total infiltration is

$$I_{n,t} = I_{n(WBM),t} + I_{s,t} \tag{6}$$

A simple representation of soil drainage was also included. We assume that if a drain system is present, all saturated infiltration also drains and soil moisture behaves as a linear reservoir where drainage is proportional ($k$) to the depth of soil moisture storage. Thus drainage $W_{d,t}$ is

$$W_{d,t} = I_{s,t} + kW_{s,t} \tag{7}$$

Soil moisture $W_s$ is then reduced by the depth of drainage prior to the next time step, but before it is reduced, the undrained soil moisture depth is used in the salt balance as described below.

*4.1.3. Salt balance*

We assume that precipitation contains no salt. Irrigation water may be assigned a concentration of salt $c_{ir}$ (mg/L). The concentration of infiltrating water $c_{in}$ is assumed to be proportional to the ratio of irrigation water to total applied water.

$$c_{in} = c_{ir}\frac{I_r}{W_a} \tag{8}$$

Concentration of salt in the soil water, and the concentration of salt in drainage water $c_{out}$, is calculated from total salt mass $M_t$ and volume of soil water plus the volume of saturated infiltration.

$$c_{out} = \frac{M_t}{\left(W_{s,t} + I_{s,t}\right)\frac{A}{100}} \tag{9}$$

where soil moisture and saturated infiltration are depths (mm) and *A* (ha) is area. The concentration of salt in the drainage water is constrained by the solubility limit of salt in water. Once the solubility limit is reached in soil water, it is assumed that excess salt exists in the soil as precipitate.

The mass (kg) of salt in the soil, *M*, is updated with salt from infiltration, which is related to infiltration salt concentration (mg/L) and the volume of infiltration ($m^3$).

$$M_t = M_{t-1} + c_{in}I_{n,t}\frac{A}{100} - c_{out}W_{d,t}\frac{A}{100} \tag{10}$$

where infiltration and drainage are depths (mm) and *A* (ha) is the area.

### *4.2. Results and discussions on simulations*

We performed daily simulations using both WBM (Vorosmarty et al., 1998) and the modified model (SaltWBM) using the same one year time series of climate drivers and model parameters to test the new model. Soil moisture estimates were similar, as shown in Figure 1. SaltWBM estimates were slightly biased upward compared to WBM. The mean absolute error was 9.7 mm and root mean squared error (RMSE) was 11 mm (28% of domain-averaged WBM soil moisture). Figure 2 shows the model outputs for the one year simulations. Although there was some difference in soil moisture behavior in the first 30 days (possibly due to differences in model spin-up), the overall behavior of soil moisture in the two models was similar, indicating that SaltWBM performs similar to WBM.

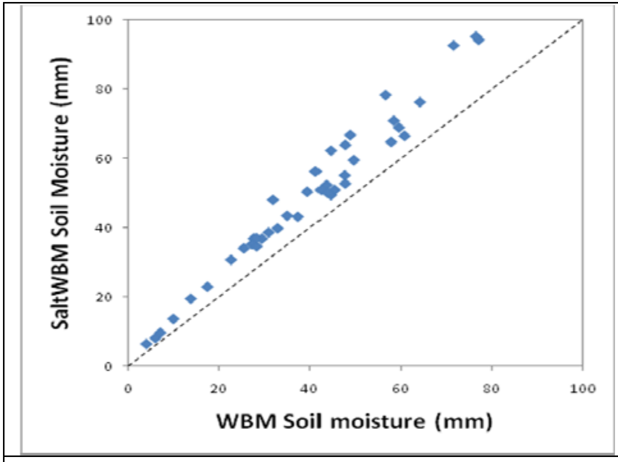

Figure 1a: Comparison of cell-based average soil moisture computed by WBM and SaltWBM.

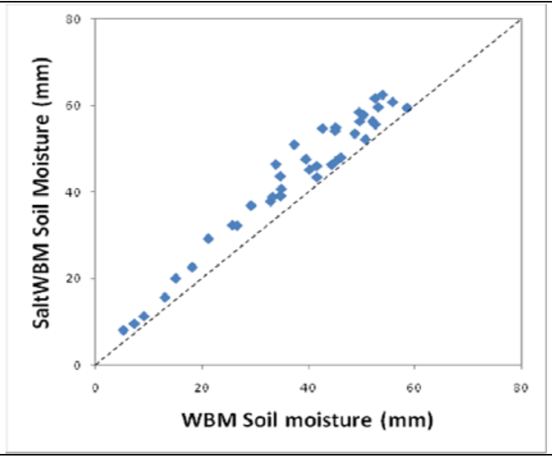

Figure 1b: Comparison of cell-based variability of soil moisture computed by WBM and SaltWBM.

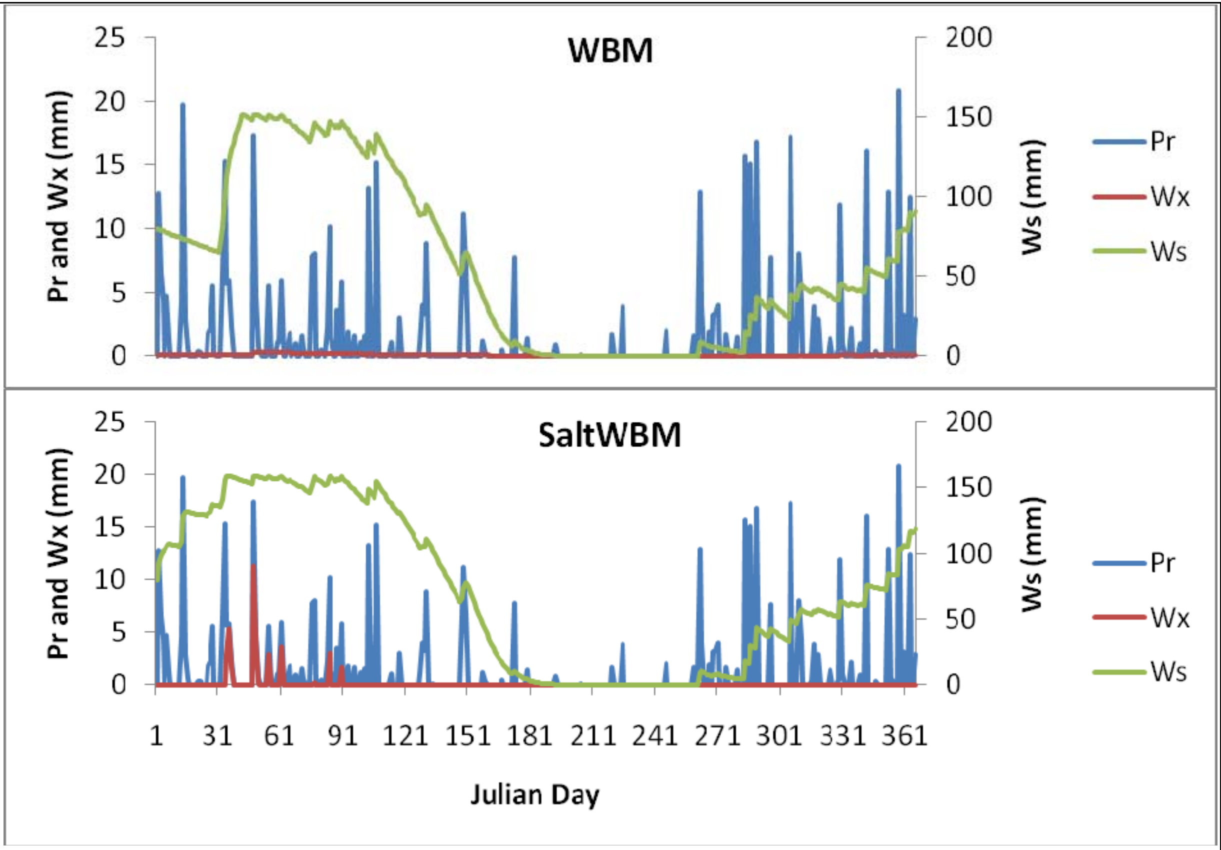

Figure 2: Comparison of simulation outputs from WBM (top) and SaltWBM (bottom).

We conducted preliminary simulations with the model by assuming an irrigation scenario in which 800 mm of irrigation water is applied at a uniform rate during a season of 100 days beginning on June 1. The soil drainage fraction was assumed to be 0.03 day$^{-1}$ and the saturated infiltration rate was assumed to be 10 mm/day. In

Figure 3, simulated soil moisture and soil drainage are shown for a few selected model cells. The irrigation period during the summer is apparent beginning around Julian day 150 when soils moisture rapidly increases. Drainage flow from the soil profile responds to increasing soil moisture due to irrigation.

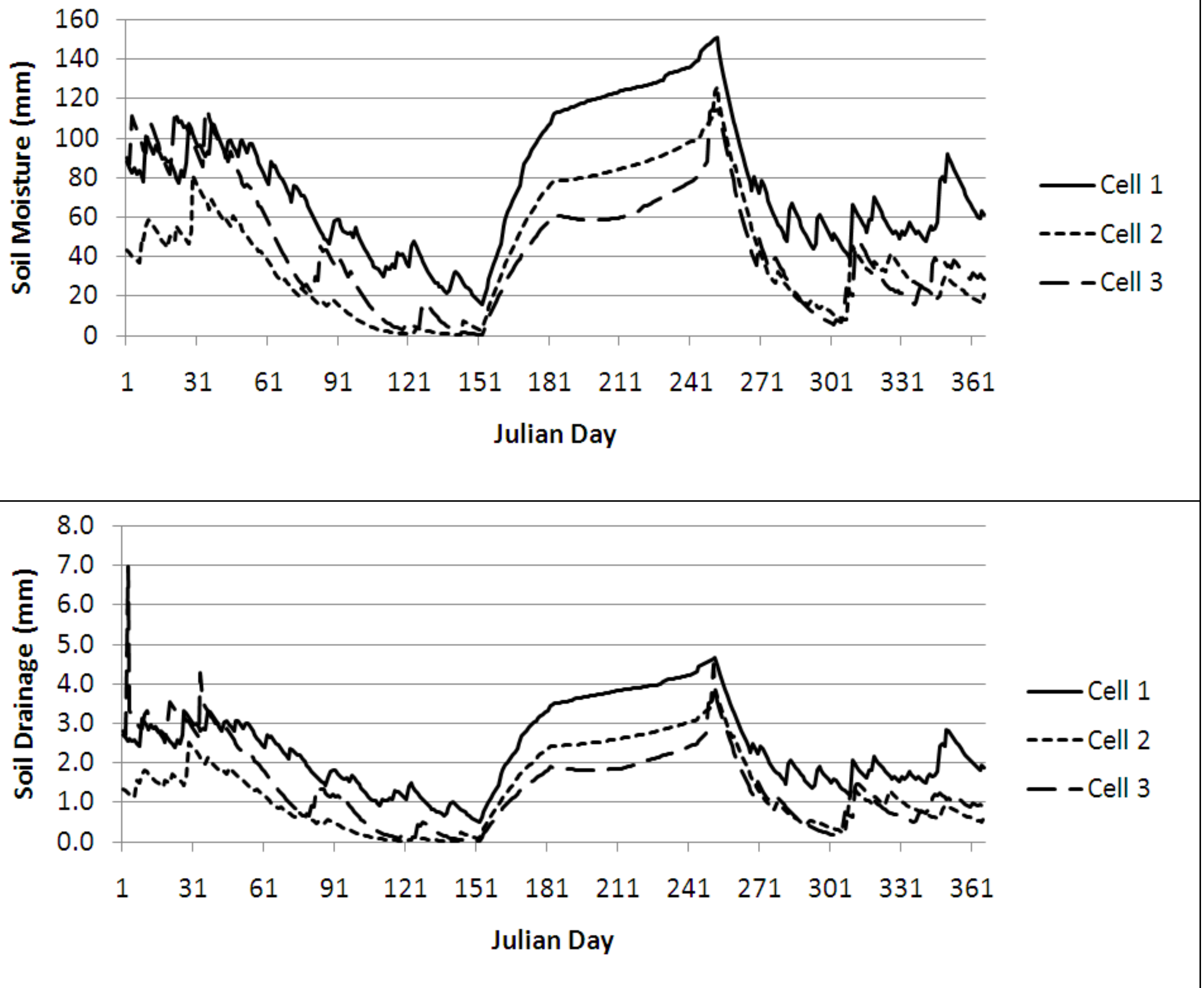

Figure 3: SaltWBM simulate soil moisture (top) and soil drainage (bottom).

Cetin and Kirda (2003) investigated the effects of using low-quality irrigation water in the Eastern Mediterranean Coastal Region of Turkey. They report that farmers without other alternatives must use low quality drainage flows having an electrical conductivity (EC) greater than 1.5. Using an approximation for the relationship between EC and concentration provided by Hillel (2000), this corresponds to a salt concentration of about 1000 mg/L. We simulated the effects of using low-quality irrigation water with this concentration and the results are shown below in Figure 4.

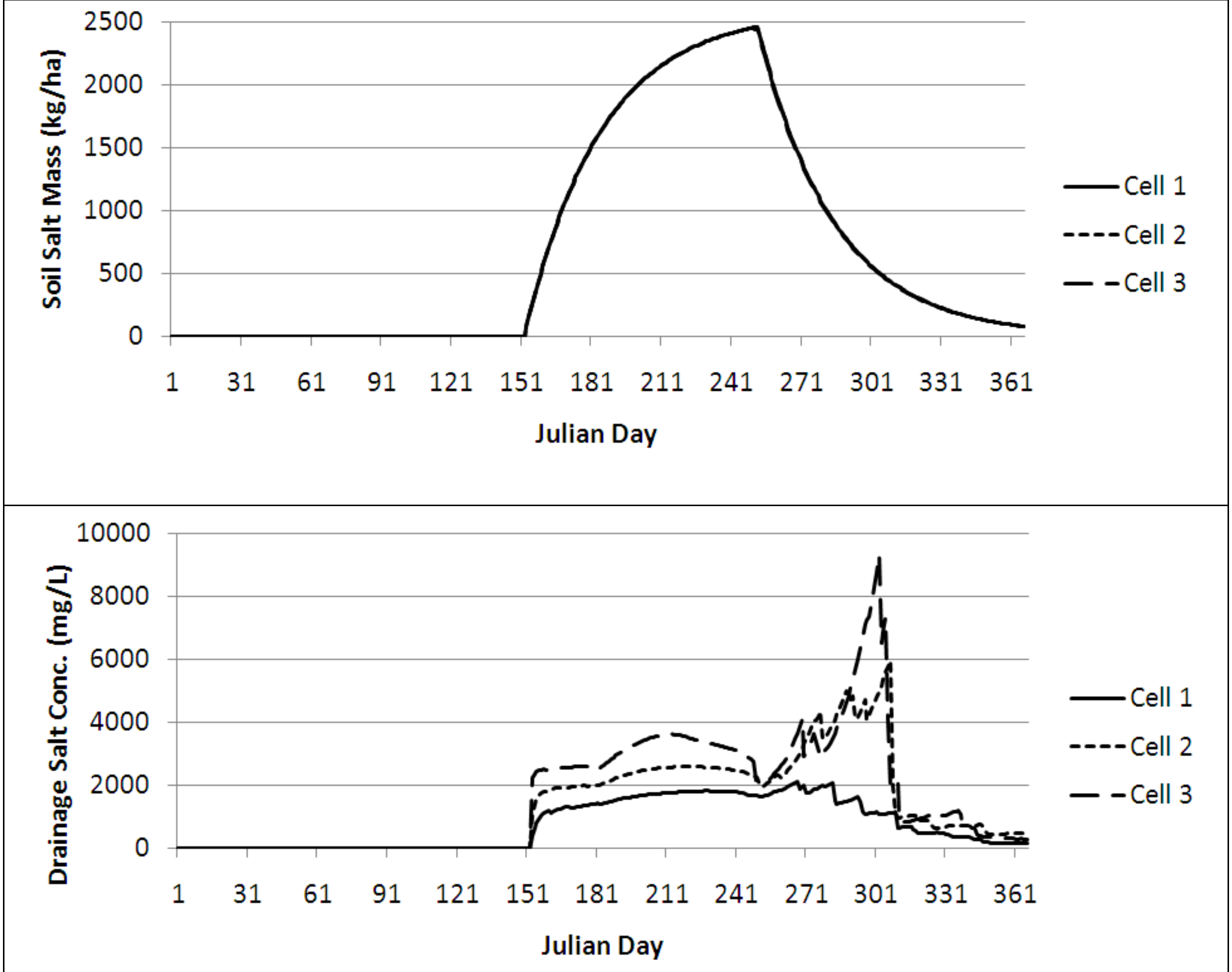

Figure 4: SaltWBM simulated soil salt mass (top) and drainage salt concentration (bottom) with low quality irrigation water (salt concentration of 1000 mg/L).

Salt mass peaks at the end of the irrigation period and decays through the end of the simulation year as salty water drains away. The concentration of salt in the drainage water is the same as salt concentration in soil water and exceeds the threshold of 2600 mg/L, which is generally believed to indicate soil salinization (Hillel, 2000), for most of the irrigation season. The peak in salt concentration is observed after irrigation has stopped and as soil moisture decreases. As soil moisture evaporates, salt remains and its concentration increases. The rapid decrease in soil water concentration after about Julian day 300 appears correlated with increasing soil moisture due to precipitation. Since precipitation is assumed to be salt free, the infiltrating rain water dilutes salty soil water. The result of using low-quality irrigation water was compared with the result of applying of high-quality irrigation water at the same rate. This high-quality irrigation water was assumed to have a salt concentration of 250 mg/L. Figure 5 shows the improvement that high-quality irrigation water can make in the accumulation of salt mass and soil water salt concentration. In this case, drainage water salt concentrations remain below the salinity threshold.

As a preliminary investigation of the effects of irrigation drainage on soil salt accumulation, we changed the drainage parameters in the model and repeated the simulations of low- and high-quality irrigation water. We reduced total irrigation depth from 800 mm to 600 mm during the summer season and assumed a soil drainage coefficient of 0.001 day$^{-1}$ and a saturated infiltration rate of 1 mm/day. These parameters were chosen to represent a poorly drained soil with a low infiltration rate. As expected, soil moisture is generally higher for the poorly drained case even with reduced irrigation input. The accumulation of salt in drainage water with low quality (1,000 mg/L salt) and high quality (250 mg/L salt) irrigation water is shown in Figure 6. As before, salt is seen to accumulate in the soil during the irrigation season and peak concentrations occur due to evapotranspiration. However in this scenario, rapid reductions in salt mass are not observed. With low quality irrigation water, salt concentrations in drainage water equals or exceeds the salinity threshold of 2600 mg/L and high salinity persists throughout the rest of the simulation. These simulation results illustrate the importance of flushing and drainage, as well as the quality of irrigation water, in reducing salt accumulation in soils.

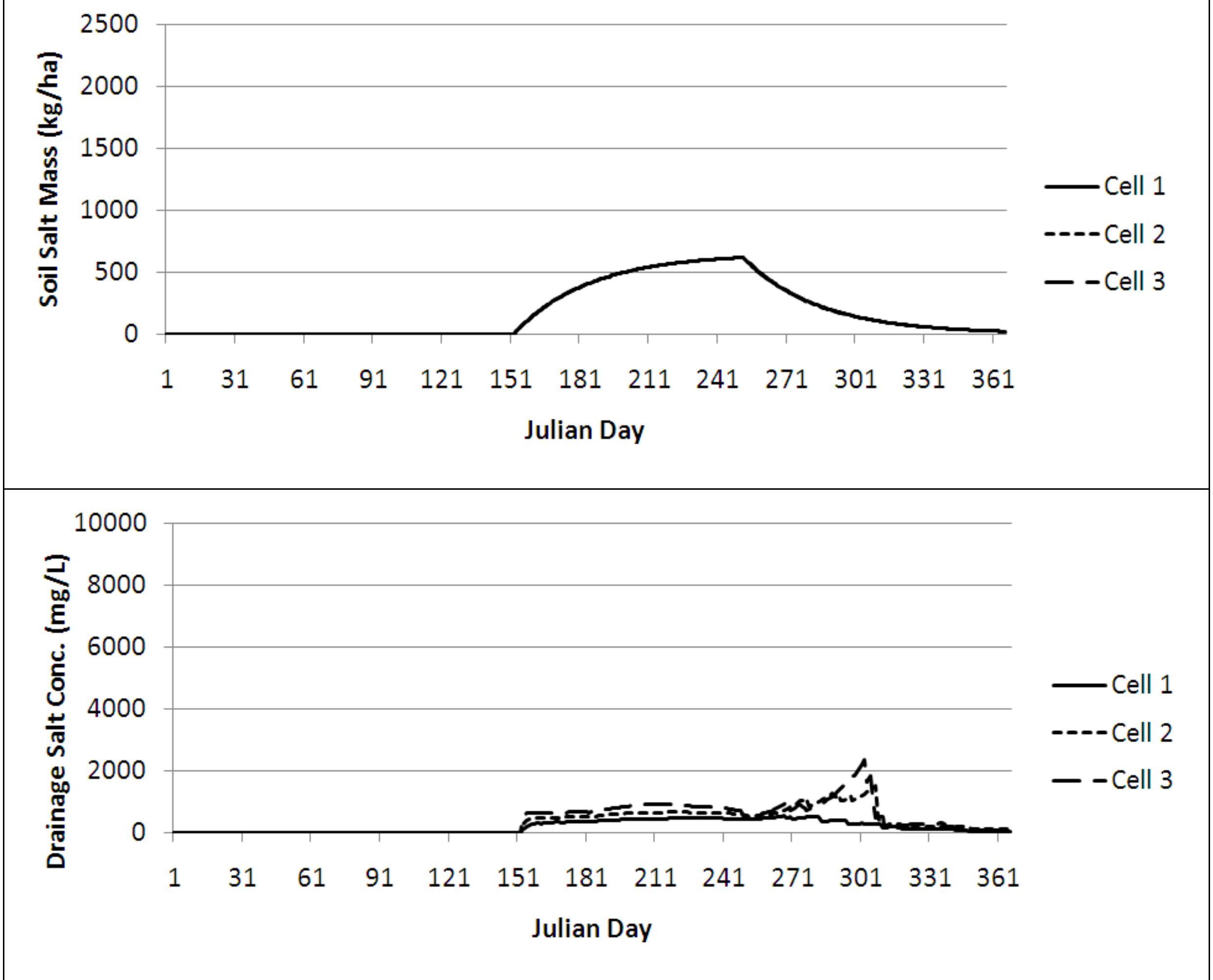

Figure 5: SaltWBM simulated soil salt mass (top) and drainage salt concentration (bottom) with irrigation water salt concentration of 250 mg/L

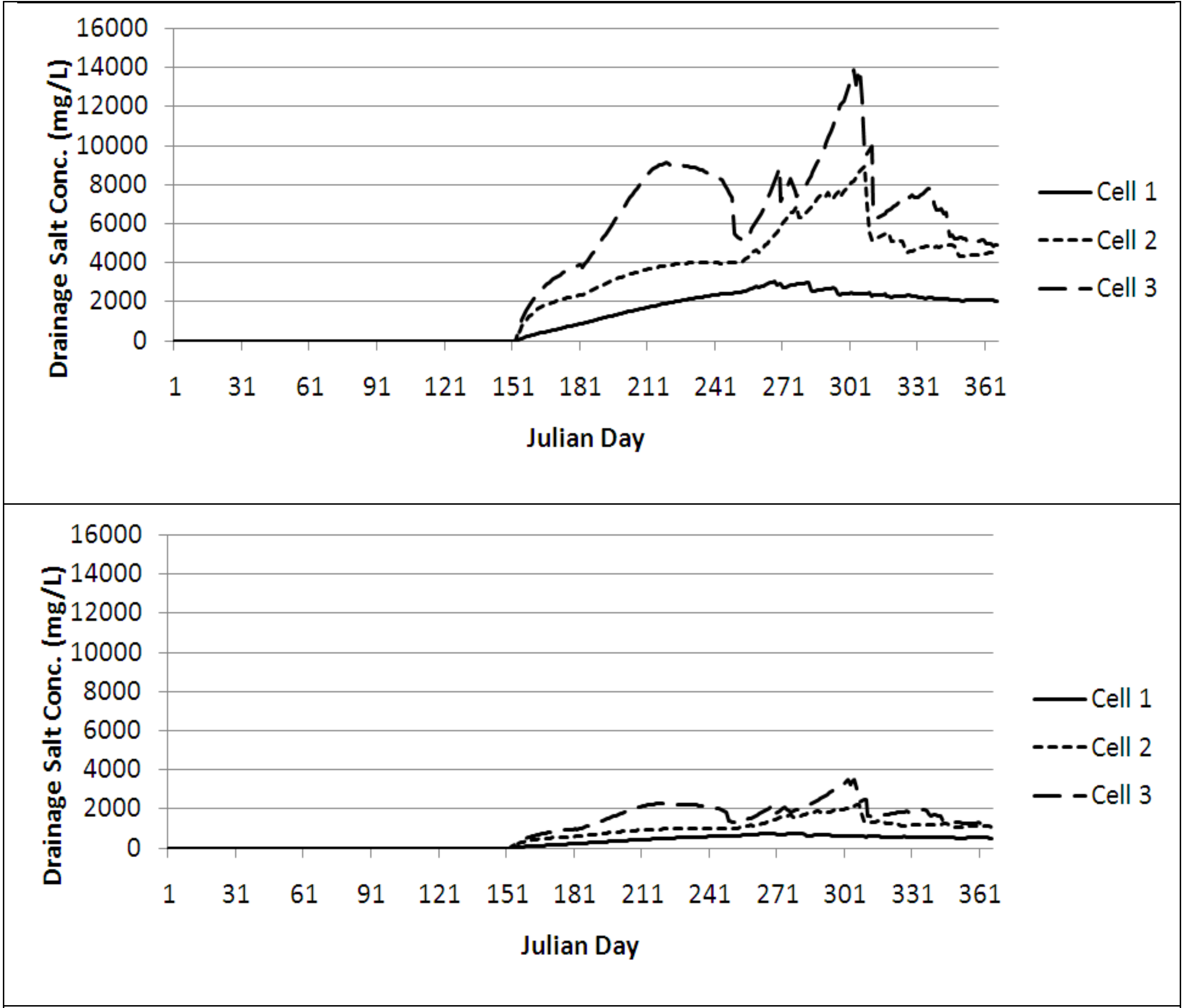

Figure 6: Comparison of salt accumulation under poorly drained conditions with low quality irrigation water (top) and high quality irrigation water (bottom).

These preliminary model simulations illustrate the impact of both irrigation water quality and soil drainage on the long-term viability of expanded irrigation. In the presence of a well-drained soil, salinity increases to high levels by the end of the growing season, but normal precipitation flushes the salinity out of the soil once irrigation ceases. However, in the poorly drained soils characteristic of the GAP region, these simulations indicate that salinity accumulates and persists, which in the absence of artificial drainage systems, could permanently degrade arable land. Future modeling scenarios will attempt to reproduce historical irrigation application and project the implications of future irrigation expansion on soil salinity in the GAP region.

## 5. DISCUSSION AND POTENTIAL SOLUTIONS

Models of successful irrigation schemes where local appropriators design, monitor, and enforce their own rules are present, but mostly in developed countries (Ostrom and Gardner, 1993)—this is not the case for Turkey. The legal framework that defines the WUAs in Turkey also does not permit this, since the rules are centrally designed and severe problems are present with monitoring and enforcement while executing the present rules.

The government has announced the Action Plan in 2008, but both the feasibility and execution of the plan are questionable. On the feasibility side, water balance calculations show that the required amount of water to irrigate such a large area may be difficult to supply and sustain. Currently, average annual water demand is estimated to be 41 BCM by the FAO, resulting in a water demand/water supply ratio of approximately 0.37, just below the 0.40 threshold that is generally accepted to indicate potentially water scarce conditions. Expanded irrigation in the GAP region could increase this ratio to greater than 0.60, well above the water scarcity threshold. Furthermore, our preliminary SaltWBM simulations indicate that expanded irrigation could lead to expanded land degradation due to soil salinization, especially given the poorly drained soils that are characteristic of this region. On the execution side, as of almost the end of 2010, the infrastructure (canals, drainage, etc) is not being constructed in parallel to what was planned. As of the end of 2009, 300,397 ha are opened to irrigation in GAP with construction ongoing on 72,093 ha. The area opened to irrigation during the Action Plan is 27,425 ha (GAP, 2009). With already present environmental problems in the region, i.e. salinity and waterlogging, a more careful planning process is required. This also includes crop diversification rather than the monoculture of cotton and switching to drip and sprinkler irrigation. The final target of GAP is irrigating 1.8 million ha of land and the respective target of the Action Plan is irrigating 1.1 million ha of land by 2012 (GAP, 2009).

For the case of Turkey, the theoretical and empirical discussion of water management shows that, in order to achieve sustainable water use, it is not sufficient to transfer the responsibility to non-state institutions such as WUAs; this may even be beyond the limits of what locally-managed institutions can do by themselves. Research on institutions shows that, while coping with both management and environmental problems, WUAs need assistance from both state agencies and market service providers (Meinzen, 2007). So, there is a need that emerges where the state bureaucracy can ensure effective monitoring of the associations while enforcing the rules and regulations that govern the locally-managed institutions. When such a legal and institutional framework is absent, it is very hard for decentralized institutions to function properly. Almost 40 percent of Turkey’s population depends on agriculture for their livelihood. Policies formulated regarding rural development need to pay attention to the above mentioned discussions (Kadirbeyoglu and Ozertan, 2010).

To cope with the ever increasing environmental problems in the region, several solutions are proposed. In addition to the institutional dimensions discussed above, these problems can also be tackled by considering the technical, managerial, educational, and governance dimensions (see, i.e. Kendirli et al., 2005). On the technical side, use of micro irrigation and drainage technologies need to be adopted—but, the burden on the farmer needs to be subsidized or financed. The managerial dimension relates with mostly volumetric pricing. But, there are both social (farmers consider water as a free good) and financial (farmers already face increasing costs of production every season) concerns related to these propositions.

And lastly, the educational dimension emphasizes lack of training programs provided to the farmers (Kün et al., 2005; Adaman and Özertan, 2007).

Adaman and Özertan (2007) discuss the need to satisfy two conditions to successfully implement these policies. The first one considers the need for a long-term vision with regard to the future of the region; decision-makers at all levels need to agree on devising and executing rules that considers the sustainable use of resources including land and water. The second one underlines the need to adopt a stakeholder governance structure with participatory decision-making and farmer initiatives in conjunction with transparency and accountability of local management.

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