GROUNDWATER STUDIES OF THE KAIDU and KONGQUE RIVER SYSTEMS.

DISCUSSION by ARY VAN DER LELY
Draft, Final

Contents.

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SUMMARY

The water and salt balance model, which is supported by a groundwater model and used for the Yangi Basin along the Kaidu and Huangshuigou Rivers has been reviewed, with particular emphasis on unsaturated flow processes and the assessment of salinity in drainage flows.

The purpose of groundwater modelling is to assess the effect of management factors and engineering options on factors of sustainability. The Yangi model concentrates mainly on the effect on river flows, soil salinity and drainage water salinity. For the latter the evaluation aimed at achieving a neutral balance in terms of salinity to the downstream environment. The objective should be expanded to include the achievement of targets further downstream.

It appears that a suitable balance of volumes in the river and of Boston Lake has been achieved, however the assessment of salinity effects is recognised to be still weak.

Two reasons have been identified why the model does not produce very credible salinity results, firstly, there are insufficient data to allow calibration and verification of the model, secondly, the lump sum parameter approach and the use of over-simplified assumptions may have prevented a higher degree of accuracy.

Several key factors in the model have been reviewed. These include the following:

- Model concepts in terms of stratigraphy, occurrence and type of aquifers
- Effect of a monthly model time step
- Effect of size of model cells on physical processes in the field
- The representation of sub-surface drainage in the model
- The concept of averaging and distributing externally made assessmens of volumes of channel seepage over the whole area.
- The effects of how field efficiency percolation and capillary rise is represented in the model.

The Yangi Water and Salt Balance Model is a lump sum parameter model, which is well constructed an executed. However because there are problems with the results in terms of salinity it is useful to examine the above factors more closely. One important aspect is that a monthly time step is not very suitable to model the effect of processes which are essentially daily, for instance irrigation applications, and factors dependent on water table depth. For that purpose it is recommended to use and develop a daily time step model, and if successful, introduce the concepts as sub-routines in the groundwater model. A preliminary stand-alone model has been prepared and is presented in the report.

Groundwater management involves the adoption of measures to allow achievement of targets and objectives. Models may be used of evaluate options. For theYangi area the current model still involves uncertainty and this suggests caution with the adoption of options which potentially have a negative downstream effect. The improvement of model prediction through data collection and verification should precede implementation of the reclamation option. On the other hand, the potentially significant positive effects of improved irrigation practices, canal lining and well pumping are recognised. Well pumping particularly may reduce artesian pressure levels in the deep aquifer, the soil salinity hazard, and seepage into drains.

The monitoring program designed for the Tarim-2 implementation and model verification has been considered and commented upon.

1. INTRODUCTION

As part of the Tarim 2 project in XinJiang province complementary studies are being conducted on the Kaidu and Lower Tarim river environments. These include the preparation of a watershed management plan for the Boston Lake catchment, assessments of the environmental needs for the Lower Tarim Green Corridor, and institutional arrangements related to water management of the whole basin. This report concerns aspects related to groundwater of the first component.

The XinJiang Agricultural University has developed a Water and Salt Balance Model (WSBM) for the Kaidu and Kongque river systems. The objective was to examine the effect of irrigation and the effect of proposals under the "Tarim 2" project for the Yangi basin. Issues relate to water use efficiency, groundwater recharge and discharge, well pumping and drainage from newly reclaimed land. The main environmental impacts being examined are soil salinity and the volume of drainage and the salt load in drainage to the Boston Lake and Little Lake system.

The terms of reference results of which are reported here were to:

- *To work with the XinJiang Agricultural University, to further develop the water and salt balance models for the Kaidu/Kongque sub-project areas by linking the model with an approach which considers the saturated zone – unsaturated zone interactions and the influence of land use on groundwater recharge / discharge.*
- *To develop a model / approach which estimates salt and nutrient loads generated by surface drainage considering factors such as groundwater levels, groundwater quality, run-off quality, land use, drain depth.*

The following aspects were considered:

- The framework of water and salt management of the Kaidu and Kongque River areas and the Lake Boston system.
- Strengths and weaknesses of the current modelling approach including verification of results.
- Current modelling concepts including the associated algorithms.
- Development of a supporting daily time step model to allow examination of specific aspects more closely.
- Required monitoring, analysis and the management context in which the Water and Salt Balance Model ought to be used.

Progress was discussed with Mr Dong of the Agricultural Universitty at several meetings. Mr Huang of the Agricultural Science Academy was another source of useful information. A field trip to the Korla area was undertaken during which local staff and management. at the Prefecture and County levels provided valuable assistance and discussion.

2. GROUNDWATER MANAGEMENT OBJECTIVES FOR THE YANGI AREA

The Yangi area receives diversions for irrigation from the Kaidu River and some other minor rivers. Waters not diverted for irrigation enter Boston Lake and the Little Boston Lake ([1]), together with surface and sub-surface drainage. The latter contains a salt load. The total volume entering the Boston Lake proper is about 1700 x $10^6$$m^3$, of which about 900 x $10^6$$m^3$ evaporates. Lesser volumes are involved with Little Boston Lake. Water from the Boston Lake is pumped into a canal, which is the main supply for the city of Korla and the Kongque irrigation areas downstream, and farms in the Qiala area during Spring.

The objectives of groundwater management in the Yangi area are in terms of sustainability. The main concerns are soil salinity, which appears to be increasing ([2]), and downstream impacts. The main downstream impact concern is salinity in drainage (Bowling, 1999). Soil salinity is a serious threat, because much of the Yangi basin appears to be underlain by an artesian aquifer, which fortunately is non-saline. Modelling of this aquifer to analyse the positive effect of solutions such as well pumping therefore is very important.

Salinity in the supply to various users and uses along the Kongque River and of Boston Lake itself is a major issue, as identified by Howard and Zeng (1999). If reclamation and development in the Yangi area continues the salinity of the Boston Lake is likely to rise significantly. Currently the salinity of the Boston Lake outflow is about 1.3 g/L. Bowling (1999) compared available water quality data with the standards adopted by the Peoples Republic of China. It was concluded that currently the standards for potable supply to Korla City are being met only a proportion of the time. Irrigation standards for water quality downstream along the Kongque River are generally being met.

The supply and field application of irrigation in the Yangi area is not efficient. Only about a third of river diversions is being used by crops. Most of the remainder is being lost to groundwater through seepage. Much of the added groundwater discharges again through non-beneficial evaporation. This causes land salinisation and waste lands. The Tarim 2 project aims at efficiency gains though canal lining, groundwater pumping, and improved irrigation practices. This would put more fresh water into the Boston lake system, and bring about an improvement. However, it is also proposed to use some of the potential gains by increasing the area under irrigation, by reclamation of salinised land through sub-surface drainage, and bringing these lands into production.

The groundwater modelling carried out has evaluated the effect of various options combinations and has concluded that there are no negative effects of the options package relative to the current scenario. There are two problems with the conclusions drawn:

1. The model verification of drainage flows and calculated versus observed salt loads is flawed by a general lack of data. This will be further discussed in this report.
2. The objective should not just be to maintain the status quo for discharges from the Yangi area, it should be linked to the long term water quality objectives for Boston Lake and downstream.

The objective for the downstream uses and users is a constraint to development proposals in the Yangi area. The option combination of improvements in salt loads discharged due to channel lining, well pumping and degradation due to reclamation and development should meet the constraint. Whilst the current lake module in the WSBM achieves a simulation of the volumes of the lake, it does not yet achieve an assessment of the salt balance, and downstream water quality.

The Yangi area Water and Salt Balance Model, may be used as a tool evaluate improvements and degradation in expected drainage water quality. Each project component may be evaluated separately or in combination. The simulation of lake salinity however is a complicated matter which is likely to require a separate modelling effort

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[1] Which are mostly reed beds (Phragmites).

[2] No data are available since the surveys of the early 1980's.

3. REVIEW OF XINJIANG AGRICULTURAL UNIVERSITY MODEL

The modelling approach used is common between a number of areas in the Tarim basin. The method is based on a simple lump sum parameter approach. This is considered reasonable for the area in question. The Water and Salt Balance Model (WSBM) has several modules including a river module, a reservoir module, an irrigation module, a groundwater module, and a lake module. The modules are linked together by common parameters. The irrigation module is central to the assessment of water table levels, drainage volumes and salt loads, and soil salinity. This module interacts via the groundwater system with river, channel and reservoir leakage, ground water pumping and sub-surface drainage. A groundwater model was developed to provide these linkages. Figure 1 shows the various factors interacting within and external to the irrigation module.

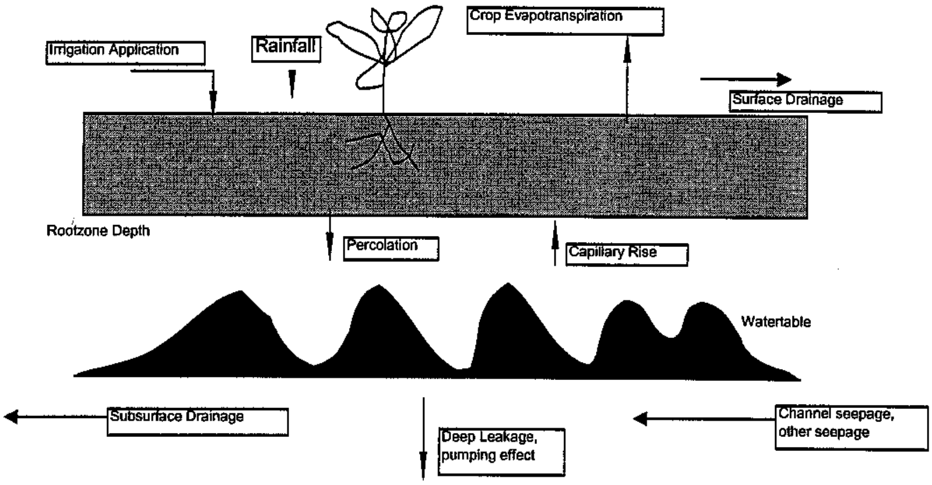

Figure 1. Main factors in the irrigation module interacting with groundwater

The model assumes that within the root zone there is full mixing of salts added or removed after each time step. This is a weakness inherent with all lump sum parameter models and not easy to overcome. The assumption has an effect on the coefficients used to calibrate the model, and may introduce some distortions.

The WSBM uses a monthly time step. The area is divided in several irrigation units, and these are further divided based on groundwater conditions and soils. Inputs from the external environment are the river diversions and salinity, and outputs to the external environment are the volumes of drainage and salt loads, plus seepage flows into and out of the river. Internally, outputs are soil salinity for different land uses and groundwater level behaviour.

It is important that this lumped parameter type model can be linked to a possible future river hydrological model (RHM), if and when these are developed. Internally, the key factors are the modelling of channel diversions, irrigation practices, ground water levels, soil salinity processes and volumes and salt loads in drainage.

The water and salt balance model aims at interpreting the fate of river diversions, evaluation of efficiency improvements, groundwater pumping options, and land development. Key outputs simulated are drainage volumes and salt loads, water table levels and soil salinity. These outputs may be compared with targets. The model also aims at identifying changes or trends in groundwater levels and land salinity.

For the WSBM simulation diversion data for the 1980-1996 period were used, the groundwater module simulation is based on the 1988-1996 period. Calibration of simulated results against observed data was carried out where possible. Sensitivity analysis was carried out to test the significance of key factor. What-if scenarios were used to test the assumptions of other factors, for instance the relationship of the depth to the water table with capillary rise and drainage rates.

The reported results indicate that the volumes of diversions and irrigation use in the model balance reasonably well, but there are problems with the salt balance and soil salinity trends. These are attributed to the inability to calibrate/verify key outputs against field observed data. To overcome the problems it is necessary to closely examine the logic of the model concepts, and the supporting algorithms.

The more detailed review of the factors in the GWM and the WSBM is presented at Appendices 2 and 3. Only the factors where a difference of opinion with the reference report exists are reported. These have been discussed with Mr Dong of the Agricultural University. Below follows a summary of the findings.

3.1. Ground Water Model

Conceptual Model.

A groundwater model needs to make assumptions regarding the layers where ground water flow occurs, and how these are inter-linked. The Yangi area model assumes a main aquifer at 30-80 metres depth, overlain by a semi-confined layer, which restricts flow between the aquifer and the water table. The transmissivity of the aquifer is quite high, about 2000m^2/day or more. The permeability of the semi-confined layer is assumed to be low, in the order of 0.01-0.1 m/day. These values vary across the district.

Discussions revealed that the pressure level in the deeper aquifer towards the lower part of the area is above ground surface (artesian). The permeability of the upper zone is quite high, in the order of 1-3 m/day, because drainage ditches may be spaced 150-200 metres apart, and the (high) channel seepage has to dissipate over some distance. This leads to the conclusion that actually two aquifers exist, separated by a semi-confined layer at about 15-30 metres depth. The Yangi model has ignored the permeability of the upper zone, which could be an unjustified simplification. The surface aquifer is the water table aquifer, which is unconfined ([3]).

Figure 1 shows the inputs of channel seepage and sub-surface drainage into the model. In fact the model did not represent these factors as lateral groundwater flows. The model assumed that sub-surface drainage would be removed as a form of deep leakage (but to drains and not the deep aquifer), whilst channel seepage volumes derived from channel flow measurements was simply added to the water table height during each time step.

Model Cell Size

The model grid cell size selected was 2.25km, which is a large size. Large cell size was necessary for practical purposes (it is a large area). Under such conditions the existence of a surface aquifer may be ignored, since there is little flow between cells, relative to the volumes of recharge and discharge occurring over one time step. However the choice of a large grid cell size has consequences, in that many of the important lateral ground water processes are internalised within each cell, e.g. the effect of channel seepage and sub-surface drainage. Lateral groundwater flow in the surface aquifer may be significant over distances of hundreds of metres. Such high flow rates occur between fields, or from channels to fields. These processes have important effects on soil salting rates in different parts of one grid cell.

Effect of Time Step.

Both the WSBM and the GWM use a monthly time step. For the irrigation module in the GWM this is a handicap, because the recharge and discharge volumes on a monthly basis are large compared to the soil moisture storage at the beginning of a time step. This in turn requires manipulation of several factors to match factors such as capillary rise, percolation to the water table, and field water use efficiency. In fact the monthly time step prevents a

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[3] See Appendix 2 for definitions of these terms.

realistic simulation. Consequently, it can not be expected that the associated salt balance will produce realistic results. The confidence in the results is small.

The use of a daily time step may overcome much of this shortcoming. Crop evaporative demand, capillary rise from the water table, soil moisture storage in the root zone and percolation can be modelled on a daily basis. As the soil moisture deficit increases, an irrigation may be applied, the volume being the deficit plus an excess above field capacity to the saturated state, dependent on the irrigation practices being adopted.

Once tested on a separate stand-alone model, the daily time step method and associated algorithms may be put in the ground water model as a sub-routine. Summarised monthly results from the sub-routine would be returned to the ground water model proper ([4]), which would still run on a monthly time step. A stand-alone EXCEL spreadsheet has been developed as part of this project to allow exploration of this alternative. It is discussed at Appendix 4.

Channel Seepage

The GWM accepts the volumes of channel seepage as an input, expressed as a proportion of river diversions. The channel efficiency is only about 50% and large volumes are involved. These volumes were determined based on measurements between river diversion points and points at tertiary channel locations. Questions arise:

- Are the river diversions accurately measured ?
- Are the measurements carried out in channels accurate?
- Can the measurements at more upstream stations be directly compared with downstream stations?
- What calibration exists?
- Are structures in the channels operated at the required conditions for accurate measurement?

These questions should be explored, because there is a linkage in the WSBM and the GWM between river diversions accuracy, channel seepage and field efficiency. For instance, if one factor is much higher than actual, the value of the other two factors may be modelled lower, and vice versa. If the volumes are wrong by a large margin, this could have a large effect on salt accumulation processes in the soil.

The problem can not be overcome by model calibration alone, since that process is merely an adjustment of factors to get an output consistent with observations (which may be wrong).

The groundwater model approach adopted for channel seepage does not reflect the fact that channel leakage is a function of the times that the channel is full or empty, rather than flow rate. The GWM may be improved to better reflect this factor.

It is also important to establish the relationship between watertable height and channel seepage in the ground water model. The simple distribution of the total channel seepage across the whole area is not supportable. The model should be adjusted to make channel seepage in any grid cell a function of water table depth, permeability and thickness of the upper ground water zone.

Drainage Volumes and Salt Loads.

Drainage volumes in the groundwater model are assessed as a function of water table depth and a "conductance" term. The conductance term in fact is a calibration factor to match calculated drainage volumes with observed volumes. Ref.2 states that there were very few observations on which to base this calibration. Nevertheless, the method provides a good tool to reflect the effect of water table height on drainage volumes.

There are no spatial data on this conductance value, neither are there spatial data regarding groundwater salinity, important when assessing the salt load originating from various sub-areas. Without such information it is not possible to make predictions of drainage volumes and salt loads from newly developed and reclaimed areas. The assumption in the model that

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[4] And therefore also the WSBM.

the groundwater salinity and the drainage volumes per unit area are the same across the whole Yangi area is questionable, since the evidence of large volumes of groundwater to not irrigated areas and non-beneficial evapo-transpiration suggests otherwise.

It is possible to calculate drainage volumes from algorithms including soil permeability, depth of ground water flow and height of water table above the average drain depth. This method calculates a value similar to "conductance" for the area in question, which after multiplication with water table height above drain depth produces the drainage volume. This volume, multiplied with the observed ground water salinity for the same area produces a more realistic estimate for salt loads from areas proposed to be reclaimed.

Capillary Rise

Capillary Rise is estimated from experimental results from the Yergiang Water Balance Experimental Station, and based on several curves for 6 different soils, ranging from loams to sand and gravel. The values obtained appear to be within a range of realistic values, however it is likely that some estimates are too high. For instance, for very shallow ground water depths the capillary rise values in the model are much higher than the rate of evapo-transpiration in the hottest month. [5] Appendix 2 shows these curves.

The ground water model includes constraints regarding the value of capillary rise used. These are realistic. There is no mention of how the effect of dry and wet soils is managed. Maximum capillary rise for a given water table depth and evaporation extraction rate occurs at an optimum moisture content between wet and dry. Such a factor could be added to the model, however it is recognised that a perfect representation without using unsaturated flow theory is difficult. It is suggested that some kind of adjustment in the model is justified.

In the groundwater model it is almost never realistic to base capillary rise estimates on an average value of water table depth for a monthly time step. The alternative approach with a daily time step, explored at Appendix 4, allows for improved assessments.

Field Efficiency.

Field Efficiency is expressed as a proportion of field diversions in the groundwater model. This concept is difficult to reconcile with a varying water table depth, and different times during the irrigation season. Since field efficiency has a major effect on leaching of root-zone salts, it is important to reflect this factor with some confidence.

Actually it is very difficult to find algorithms which can represent field efficiency accurately, because irrigation practices vary widely, both spatially and between crops. For the daily time step stand-alone model discussed at Appendix 4 a method was used whereby soil moisture is depleted by evaporative processes to a certain point (e.g. 50mm), after which irrigation restores the soil water content to saturation. The excess above field capacity then drains out over the next day, unless the water table is already high within the root zone.

3.2. WATER AND SALT BALANCE.

No significant issues were found requiring alterations to the model. Minor issues have been discussed with Mr Dong of the XinJiang Agricultural University. These include:

Calculation of Surface Drainage. The concepts used are believed to be too complex. Perhaps it is better to use a simple proportion of field diversions, e.g. 4%, based on observation of practices.

Reservoir Salt Balance. This equation may be improved, as stated in Ref1.

Soil Salinity Irrigated Fields. The solutions to differential equations used are quite complex and there is still doubt regarding applicability. The daily time step approach discussed at Appendix 4 may solve this problem.

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[5] This is possible. The soil remains wet to the soil surface despite evaporation.

Lake Module . The Lake module assumes full mixing after each time step. It is recognised that this produces unrealistic results in the simulation of data over a period. Whether there is full mixing or not, the long-term equilibrium involves that all salts in are equal to salts out, and the average outlet salinity will reflect that average. It is believed that currently the lake salt balance is about in equilibrium. If inflow and outflow volumes are known accurately, the average annual quantity of salt attributable to drainage should not be too difficult to determine. Uncertainty exists however with the groundwater volumes into and out of the Boston Lake.

The lake evaporation factor should be added to the equations of Ref.1.

4. USE OF GROUNDWATER MODELS AS A MANAGEMENT TOOL

Models are tools for decision making. Large public infra-structure investment decisions such as the Tarim 2 projects require the cooperation of many agencies and even community input. Models, which systematically reflect the framework of linkages between factors, are very useful towards a better understanding of the physical processes and the impact of project option combinations. Such information is needed to help individuals and agencies towards positions during negotiations, thereby also taking into account other aspects not part of the model outcomes.

In a participatory decision making environment the challenge is to convey data and simulation model outcomes in a useful manner for evaluation of "what if" scenarios for resource use and management strategies. Economic and social factors together with biophysical simulation modelling are important components in decision making (Shaw, 1998).

There are several problems to be dealt with. Simulation models of a catchment scale are needed, but data are usually collected for individual sites. Research results are usually applicable for sites only. The scaling up from small scale to large scale involves large potential errors. Calibration of factors may achieve simulation of key factors, but may distort the value of other, internal factors. The confidence of model results should always be questioned.

Simulation of complex processes is a compromise between simple lump sum parameter models and complex multi-parameter models. For the latter the values of parameters cannot easily be determined and calibration is usually difficult.

In the Yangi area of the Kaidu and Huangshuigou Rivers area the key performance indicators for natural resource management appear to be:

1. Volumes of River diversions, or, the volumes of water not used by the irrigated areas.
2. Groundwater pressure level in the deeper aquifer at 30-80 metres depth.
3. Groundwater levels in the shallow groundwater system within 15 metres from the surface.
4. Soil salinity for different cropping systems.
5. Drainage water volumes.
6. Drainage water salinity and salt loads.
7. Volumes and salt concentrations in Boston Lake and the Little Lake.
8. Nutrients, biomass and biocide residue discharges to Boston lake

The main management uses perceived for the models are:

- Evaluation of alternative project options, such as well pumping, channel sealing, improved field efficiency, and reclamation and development of additional land.
- Re-evaluation of scenarios as more calibration data become available and it is possible to upgrade model coefficients.
- Evaluation of new project options, not yet approved.

These evaluations have to meet the constraint that salt loads to the Boston Lake generated allow the achievement of the long term objective for the salinity of its discharge (e.g. 1 g/L).

The model may be linked to a river hydrological model, which links the impacts between more upstream reaches and downstream reaches. This is being considered as part of this project (Black, 1999)

The model is not perceived to be suitable as a performance monitoring evaluation tool. The entering of annual data of groundwater, drainage discharge, etc. and evaluation of these against a target or the baseline for a reference date does not appear feasible. There are too many factors for which values are estimated at present. The model uses averages for these factors mainly. However there may be an opportunity to test the sensitivity of specific factors, for instance the effect of a sequence of dry years on drainage flows. Using the same principle, it may be used to test the measures that are necessary to achieve specific targets, for instance the salt load reduction necessary to achieve a downstream water salinity standard.

Before these possibilities can be practised however, there needs to be sufficient confidence the models are producing credible outputs. This is still lacking at this time, especially with salinity in soils and in drainage flows. The data sets used to verify the models are being questioned with regard to accuracy, and for salinity there simply were not sufficient data to use. Data available include river diversions, a few groundwater depth observations of the 1980's, a few drainage volume observations (also from years ago), a few groundwater salinity data, and levels in Boston Lake. The salt balance did not add up well, and there is little confidence in the results.

Soil salinity data were collected during the early 1980's, but not since that time.

It is concluded that there is still doubt on the general conclusion that the selected combination of Tarim-2 projects will not result in an adverse effect on the salt balance. It is even more uncertain whether the outcome is consistent with downstream water quality standards. This leads to the conclusion that groundwater management, especially the adoption of options with a negative effect on drainage water salinity, should proceed with caution. A cautious management approach would be to not allow progress of such projects at the present time. This would apply until there is increased confidence that the downstream targets can be met. This may take a few years of monitoring data collection and model verification / improvement.

Once this phase has been completed the WSBM may become an effective decision support tool to evaluate projects. For new areas to be reclaimed and developed the proponent should submit to the approving authority a proposal with data and analysis of key factors, such as ground water salinity, current soil salinity, deep pressure levels, and water table levels ([6]). These may be evaluated with the WSBM and GWM to decide on downstream impacts. A decision regarding approval can then be made after review of all stakeholder agencies.

This process would not apply to the channel lining and well pumping options ([7]), however performance data should be collected to determine that the positive effects claimed are indeed being realised. The model coefficients may require adjustment to reflect the observed performance. The extent of implementation of projects with negative impacts has to be matched (and bettered) by the performance of projects with positive impacts.

5. MONITORING REQUIREMENTS

The groundwater model report recommends a monitoring schedule to achieve most of the perceived shortcomings discussed above. The following notes are added:

Climate: No comment. It is not certain seven stations are necessary. The measurement of evaporation should be based on large evaporation pans, or calculated as ET Penman from radiation measurements, temperature, wind run and humidity.

Surface Water Monitoring. The calibration of channel measurement devices such as weirs was mentioned at section 3. Channel measurements are part of operations, not just for the seepage assessment. The monitoring of drains should occur fairly frequently, say once a week during the main irrigation season, and not monthly, because flows vary with water table levels, which fluctuate considerably. A system of collection of water samples in dedicated clean bottles with analysis in a laboratory is preferred to the use of portable salinity meters, unless a good system of regular calibration of these instruments exists ([8])

Groundwater Monitoring: The number of piezometers identified appears sufficient, considering the large transmissivity in the aquifer. Piezometers need to be monitored for two purposes, analysis of the regional effect, producing groundwater maps and statistics for the region, and for analysis of seasonal effects, producing groundwater hydrographs for the year. For the former the piezometer set needs to be read only about twice a year. For the latter

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[6] This means the proponent and the approving authority should not be the same.

[7] Because these are positive impact options.

[8] Despite this, portable EC meters should be a significant component of salinity management and be available to field personnel.

only few piezometers need to be used, read bi-monthly. Monthly observations are appropriate for new well fields for the first few years of operation, commencing the year before operations.

Soil Salinity: The monitoring program of Ref.2 appears suitable, but the number of sites for soil salinity monitoring should be increased to at least 50 per sub-region, to overcome spatial variation and to get an average which can be compared against the previous sampling average ([9]). It may be noted that it is not necessary to carry out full analysis on all samples collected ([10]), since a simple analysis of 1:5 soil water suspensions is a sufficient guide. This sampling is necessary about once every 5 years. The analysis may consist of the comparison percentile ranges, proportion of samples with salinity above certain levels etc. Appendix 1 provides comment on the types of salinity units that may be utilised.

Matters such as nutrients, biocides etc are outside the scope of the WSBM

6. REFERENCES

1. Dong, G.g. et al "Water and Salt Balance and Groundwater Model", June 1997 (Ref.1)
2. Dong, G. et al. "The Water and Salt Balance Model Study Report". WR Scientific and Technical Service, XinJiang Agricultural University, Bayangol World Bank Project Office (Ref.2).
3. Black, D. "Hydrologic Modelling of the Tarim Basin" OPCV report, May 1999.
4. Bowling, L., "Hydrology, Water Quality, and Environmental Conditions in the Boston Lake / The Small Lake and Reed beds, and the Kongque River Downstream". OPCV report, 1999.
5. Howard, M., Zeng, C. "Integrated Environmental Management in the Tarim Basin Area – Waste Water Management Review – Boston Lake / Kongque River", OPCV report, 1999
6. Peoples Republic of China. "National Standards on Environmental Protection". 1989.
7. Shaw, R.,.. "The Role of Modelling in Natural Resource Management". Workshop MDBC on Use of Models in Natural Resource Management, Melbourne, Australia 1996.

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[9] The actual number should be based on an analysis of spatial variation in soil salinity, e.g. variograms of correlation and kriging analysis

[10] This appears to have been the practice in the past, resulting in high costs.

APPENDIX 1

SOIL SALINITY AND CROP PRODUCTION

Soil salinity may be expressed in different ways, as parts per million (ppm), as g/L in soil moisture, or as electrical conductivity (EC) of a soil water paste (as dS/m). The water content of the soil at which salinity or EC is measured is very important. For groundwater the salinity is expressed for the water content at saturation in the field. For unsaturated soils it is common internationally to prepare a soil water paste, and extract moisture by centrifuging. The salinity of this extract, expressed as electrical conductivity (EC) is called $EC_{extract}$. This method is time consuming, and many field observations are based on a simple 1:5 (dry) soil / water ratio, of which the salinity may be called $EC_{1:5}$. Research is needed to determine the conversion factors from $EC_{1:5}$ to $EC_{extract}$. Once completed, large numbers of samples can be analysed at low cost.

The international literature regarding crop tolerance to salinity uses $EC_{extract}$ as the standard moisture content. Tables are available which show yield decline with increasing values for $EC_{extract}$. Table 2 below was prepared by CSIRO, Land and Water, Australia. Alternatively, see web site *//www.colostate.edu/Depts/Coopext/PUBS/Crops*

In the groundwater model for the Yangi area the reference soil moisture content for calculating salinity is field capacity. It is probable that there is a good correlation between the soil moisture content at field capacity and at saturation extract. This is fortunate, because it means that the salinity at field capacity can be used for a check on crop tolerance.

The moisture content at field capacity is likely to be 50-67% of the moisture content at saturation extract. Hence the values in Table 2 should be increased by 50 to 100% for conversion of $EC_{extract}$ to $EC_{field\ capacity}$.

The salinity at field capacity in the models is expressed as g/L. To convert from dS/cm to g/L, use a multiplier of about 0.6 ([11]). Also see Table 1 below.

An approximation of the crop tolerance limits at field capacity in g/L therefore are the values of the $EC_{extract}$ multiplied by a factor in the order of 1.0 to 1.3.

Water salinity and the chemical composition of salts may also have indirect effect on crop production, through their effect on soil structure and hence soil porosity. There may also be specific ion effects resulting in crop yield effects. These two factors are not believed to be of a large consequence in the Yangi basin with its sandy soils, and are not further considered here.

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[11] This depends on the chemical composition of the salt in the soil.

APPENDIX 2

GROUNDWATER MODEL REVIEW.

1. Conceptual Model.

The Yangi area model assumes a semi-confined aquifer at 30-100 metres depth. This layer conveys all groundwater flow, from the upstream areas into the Yangi areas. The aquifer has a variable transmissivity ([12]) in the order of 2,000 m^2/day. Well pumping would occur from this aquifer. The aquifer looses or gains groundwater by leakage to the overlying layer, which in the model is perceived to be a semi-confining layer of thickness 15-30 metres. [13], The confining layer is assumed to reach the soil surface. This means that the horizontal flow in this layer is assumed negligible and was not modelled.

The water table near the soil surface is located in the semi-confined layer

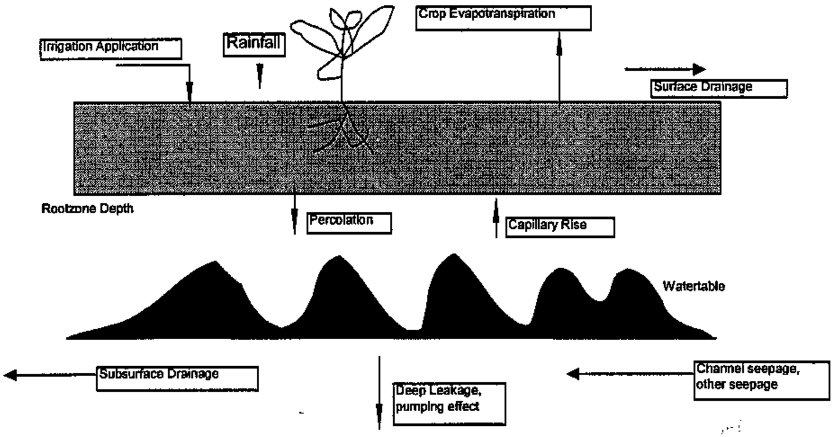
Several aspects are very important to the correct functioning of the groundwater model (GWM), and its results in the Water and Salt Balance Model (WSBM). Most concepts adopted appear to lead to appropriate interpretation, however questions arose regarding the following:

1. The way in which the various soil layers are represented in the model, and how the modelling is carried out for each layer.
2. The time step in the model.
3. Model cell size

1.1. Configuration.

The model concepts and functions are described in Ref 1. The model is a two layer model with a semi-confined to confined aquifer at about 30-100 metres overlain by the semi-confined zone, in which the watertable occurs.. It is asumed that the surface layer conveys no flow laterally, it is asumed to have low permeability. All groundwater flow occurs through the main aquifer. Water movement between the water table and the main aquifer is by vertical leakage

Figure 1 shows how this was conceptualised.



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[12] The capacity of the aquifer to convey ground water (permeability times thickness).

[13] The term semi-confined aquifer means the overlying layer has limited permeability and allows leakage. This is distinct from un-confined aquifers, which behave like a water table aquifer, and confined aquifers, which are overlain by a near impermeable layer.

Note: Figure 1 shows the sub-surface drainage and the channel seepage components as lateral inputs. This is not strictly correct since these factors were modelled in a different way, see below.

A definition of some definitions may be appropriate. An aquifer is unconfined when its pressure level is the same as the water table, fluctuating freely. It is exposed to atmospheric pressure at its upper limit. If an aquifer is confined, the pressure level in the aquifer behaves (nearly) independently of the pressure levels in higher of deeper aquifers in the profile. The aquifer is like a not leaking pipe adjacent to another pipe. A semi-confined aquifer is bounded by layers that leak slowly, in other words, the pressure level in the aquifer adjusts slowly to the pressure levels in adjacent aquifers because the intermediate layers leak. The semi-confined layers may be called an aquitard.

For the Yangi model the concept of no horizontal flow in the shallow aquifer is questioned. The surface horizons are sandy and permeable, certainly more permeable than reflected at Figure 4.4 of Ref1, which show the permeability to be about 0.01 to 0.25 m/day.. Field evidence shows that drainage spacings to control water tables are 100-200 metres, indicating significant permeability in the subsoil.

A grid of cells covering a rectangular area was developed, with cell size 2250 metres. Hydro-geological input parameters include aquifer permeability (k) and its thickness (D), the permeability of the unconfined aquifer, the storage coefficient of the aquifer (0.001 to 0.012) and the specific yield of the unconfined aquifer. On the other hand, it appears that there is a large pressure head difference between the shallow aquifer and the deeper aquifer. In parts of the lower to middle reaches of the Yangi area the deeper aquifer pressure is about 2-3 metres above ground surface, but the shallow watertable is at about 1-2 metres below the ground surface, showing a difference of up to 5 metres (Mr Huang, personal communication). This indicates upward leakage, contributing to high water tables.

The report Ref.2 shows a pressure level map, but no map showing depth to soil surface. The existence of large pressure differences between the semi-confined layer and the water table aquifer near the surface is very important, emphasising the need for well pumping where groundwater salinity is low.

It is concluded that a less permeable layer exists at about 15-20 metres depth, but that the surface layers are more permeable, constituting an unconfined water table aquifer. The transmissivity of the deeper aquifer appears to be in the order of 2000 m^2/day and higher. The transmissivity of the surficial layer would be about 30-40 m^2/day if the permeability is about 1.5-2.0 metres/day and the thickness about 15 metres (14).

1.2. Time Step.

The groundwater model uses a monthly time step. Input are the water table level, soil moisture and other values from the previous time step, then additions are calculated from leaching, capillary rise, drainage, channel seepage and other factors, and then the end of time step situation is assessed.

Whilst the volumes into and out of the groundwater system after calibration appear reasonable, it was found that the salt balance of the unsaturated root zone does not produce credible results. The water balance of the root zone calibration is based mainly on the observation that the water table trend should be flat, and the order of magnitude of the various recharge and discharge values.

It is clear that the volumes into and out of the root zone and to and from the shallow ground water are large compared to the initial values at the beginning of the time step, particularly in summer. For instance, the soil moisture availability at the beginning of the month may be 100mm, but the irrigation over June may be 200mm, drainage 30mm, the crop use 150mm, the leaching 80mm, the capillary rise may be 60mm, etc. The water balance is that soil moisture is still 100mm at the end of the month, but is is probable that the root zone salts are also still the same?

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[14] These values were confirmed as reasonable by Mr Dong, of YinJiang Agr. Uni.

For the water table this is even more critical. It will rise and fall over the monthly period, and this will produce responses in terms of sub-surface drainage volumes. It is unlikely this can be adequately represented by an average watertable depth, especially if the beginning of time step is chosen ([15]), rather than the average during the time step.

For the assessment of soil salinity at the end of each time step a differential equation was developed. Because the capillary rise cannot be adequately be represented by reference to an average watertable over a month period, the validity of these equations is also in doubt.

From this discussion it may be concluded that it is useful to examine the use of a daily time step in the groundwater model to increase accuracy of the process being modelled. The daily time step would be applied only to the processes for which this appears important, which is the water movement into and out of the root zone and into and out of the shallow groundwater. After running such a model on a daily time step, the results are then summarised in a monthly format, and fed back into the groundwater model, to calculate flows between cells using the monthly time step.

The above methodology is fairly standard in groundwater modelling, and could be used for the Yangi basin. However, it is useful to first examine the concept using a separate stand-alone model, for instance in EXCEL spreadsheet format. After all, the daily time step model may require the use of additional factors and coefficients, none of which can be verified against actual data or research results in the Yangi area. Based on the outcome of the examination, the main features of the daily model may be added as a subroutine to the groundwater model in FORTRAN.

A stand-alone model as suggested was developed and used to critically examine several factors, such as water table variation, soil moisture changes, soil salinity, and sub-surface drainage for a land use unit. It is described in Appendix 4 and capable of using a sequence of crops over four years. It also includes aspects of other factors in the groundwater model yet to be discussed, including assumptions regarding capillary rise, irrigation volumes, channel seepage and drainage, as well as soil salinity aspects and drainage salt loads.

1.3. Model Cell Size

The WSBM is based on irrigation unit areas, and sub-areas dividing these in water table depth zones and soils. This is considered reasonable. The groundwater model linking with the WSBM uses 2.25 km cell size. This size appears to be based more on the scale of the total area rather than a relationship with field size, cropping areas or otherwise. The Yangi area is a complex matrix of land use and farm size, which probably is impossible to capture with accuracy. Therefore the ground water model had to compromise in this regard.

Gradients in the Yangi landscape are about 0.001. This means that for large cell sizes the groundwater flow through the surface layer into and out of a model cell ([16]) may be small relative to the recharge and discharge factors. On that basis the horizontal flow between large model cells may be small and may be ignored. However, there is a surface aquifer with significant permeability and groundwater flow between fields, from fields to drains, and from channels to fields is significant. The distance of these type of flows is expected to be in the order of hundreds of metres to a kilometre, perhaps more. This does not cause much flow between large cells, but it means that the groundwater model has internalised many important processes within the area of each individual cell.

The consequence is that within one cell there may be up to three different land uses, irrigated (a variety of crops including rice), not irrigated by having water use nevertheless (e.g. trees), and not irrigated, bare. Where within a cell the water table varies significantly for these different land uses, it is likely that significant ground water transport between uses occurs, for instance to the tree areas, or to the bare waste areas. The existing groundwater model makes an assessment for all these zones based on groundwater transport through the deeper aquifer and upward/downward leakage, however the groundwater transport through the shallow aquifer identified in section 1.3.1.1. has not been modelled.

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[15] This is usually the case with simplified models.

[16] The model cell size used was 2.25 by 2.25 km.

There are other consequences. For instance, if it is considered that the non beneficial evapotranspiration of the waste areas is correct, then the source of this may have been derived from either upward leakage from the deep aquifer, and from lateral leakage through the shallow zones. If the latter is higher than assumed by the model, then the upward leakage would be less. This issue raises the probability that the "conductance" of the aquitard is less than adopted in the ground water model following calibration.

1.4. Flow Between Cells

The flow between cells is computed using a standard method, considering the water table height in each adjacent cell, the harmonic permeability between cells (SQRT(k1*k2)), and cell size. The groundwater height of the cell and the adjacent cell is used. From Ref.1 it was not clear whether these heights relate to the beginning of the time step, the end of the time step, or whether it is an average over the duration of the time step. The latter is preferred for accuracy in any groundwater model, but requires an iterative calculation procedure, since not all cells are calculated at once and the end of time step groundwater height is changing for every calculation.

Most groundwater models use special (relaxation) methods to achieve rapid convergence for the calculated end of time step groundwater height with as few iterations as possible to achieve an agreed accuracy. Ref.1 above does not indicate what iterative procedure is used, if any.

The matter was discussed with Mr. Dong, who assured that the correct procedures were used including iterations. Often there were more than 50 iterations per time step.

2 Drainage Discharge

The main factors are groundwater depth above drain depth, depth of drain, and "drainage conductance", which are multiplied with each other. This term is similar to the conductance used for the calculation of upward leakage from or downward leakage to the deeper aquifer, however whilst the latter values are specified at table 4.4 of Ref.2., the values for drainage conductance appear mostly artificial. There is no actual leakage to the deep aquifer.

Most parts of the lower to middle Yangi basin have sub-surface drainage, systematically installed. Drain spacings of about 100-200 metres are common, with drain depths of about 2 metres. The length of many drains is 500-1000 metres. Most drains are open drains, but one State farm appears to have used a machine to install sub-surface drainage using horizontal pipes at about 2 metres depth ([17]). This information permits the use of analytical methods to calculate volumes of drainage based on the drain dimensions, permeability and water table height.

The most basic sub-surface drainage equation is q= 8kDH/L2, with q is drainage rate (m/day), k is permeability (m/day), D is thickness of conductive zone below the water table, H is water table height above the drain at the midpoint between drains, and L is drain spacing. In this 8kD/L2 has a dimension the same as the conductance term referred to above. This indicates that the method used in the model is acceptable and very simple. It is suitable for situations where the model is being calibrated against observed drainage flows.

The alternative proposed has more potential for new projects, for which the flow data do not exist, but there is knowledge regarding the soil profile, its permeability, and the drain spacing.

Since presently data are scarce for all factors it is concluded that the current technique may have an advantage over the alternative, because drainage flow data may be more easy to obtain in the Yangi area than soil permeability data. The conductance value in the groundwater model should be calibrated against flow for all major drainage areas ([18]).

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[17] Mr Huang, personal communication.

[18] Once the conductance is known, it would be possible to derive the kD value (transmissivity) by analysing the water table depth against flow rates.

If drainage volumes are monitored together with the monitoring of average watertable levels for a set of dates, then it is possible to derive value for the transmissivity of the upper surficial layer. This in turn would give information whether the groundwater modelling concepts are soundly based (*section 1.3.1.1*)

1.3.4. Supply Channels

The groundwater model treats groundwater seepage as input based on the river diversions ([19]). The canal efficiency is the main input, and the seepage is (1- CEFF) * RDIV.

Figuer 1 of this Appendix shows channel seepage as a lateral inflow, but this is not correct. In fact the channel seepage is just added to the height of the water table at each time step (month).

The efficiency of channels has increased from about 40% to about 55% following the lining with plastic or concrete of about 75% of the secondary and tertiary channels. The quaternary channels are not treated ([20]). Mr Huang (ASA) believes that main canals get priority for treatment with lining, and that canal efficiency may improve to 70%.

The volumes of seepage are very large. Most can only be accommodated in the groundwater system by increased capillary rise, which will tend to bring salts into the root zone. There is uncertainty regarding the accuracy of the channel efficiency estimates, which are based on the difference between diverted volumes and volumes delivered to tertiary or quaternary groups. The confidence limits of the estimates is assumed to be about 75% (Ref 2).

River diversions are checked against river flow data at subsequent river gauging stations. From the information available this appears to be carried out systematically and in a detailed fashion, hence the estimates of river diversions should be reasonable correct ([21]). Between the river and the crop, the losses comprise reservoir losses, channel losses and field losses. If the channel losses are over-estimated by the methods used, then field losses may be under-estimated, and vice versa.

Since a lot of the Tarim 2 investments are in channel lining, and less so in water use efficiency on farm, it appears useful to check the calibration of the types of weirs used in the channel system. Well maintained and less well maintained trapezoidal concrete weirs with sills were shown on the field visit. The measurements are from a gauge just upstream of the weir. Is it certain that the weirs are not "drowned" at the downstream end, affecting measurement? Has calibration been carried out regularly? The structures upstream of the weirs, which are underflow regulators, may be able to be used for this purpose.

The large volumes of channel seepage should be sanity checked against analytical models. Channel seepage is a function of watertable depth, and this factor should be part of the groundwater modelling. The simple distribution of a percentage of river diversions over the whole area ([22]) is not believed to be correct. Channel seepage is a function of when channels are filled, not necessarily a function of river diversions.

Analytical equations to assess channel seepage are not simple (e.g. see Kirkham, 1963, or van der Lely, 1998) ([23]). For that reason it appears practical and efficient for the Yangi area to use an approach similar to that for sub-surface drainage, using a conductance term multiplied with the average channel level height above the water table and with the area. This will ensure that channel seepage is higher in the deeper water table areas. The value of the conductance being used would be based on calibration of the input values for channel seepage derived from flow measurements, but the conductance term found may be compared with that for sub-surface drainage. Both values should be of the same order for each sub-

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[19] Ref1 actually refers to Field diversions, however this was corrected by Mr Dong.

[20] Yangi Water Resources Bureau (Mr Fong).

[21] However there are alternative views which consider that the calibration of river gauging methods also require confirmation.

[22] Excepting the main canal (Mr Fong)

[23] The latter review report is being provided to Mr Dong.

area. This procedure will provide a method to judge whether it is likely that channel seepage estimates from flow measurements are possibly over-estimated or otherwise.

1.3.5. Field Efficiency and Capillary Rise

The assessment of field percolation losses is based on a proportion of field diversions, which is reasonable. The capillary rise (CR) in irrigated, not irrigated and dry lands is based on equations from field investigations, also reasonable. Report Ref.1 provides some constraints on capillary rise, for instance it should not exceed crop use, and it relates to the depth of the root zone.

The capillary rise estimates are based on experiments at the Yergiang experiment station. These are shown at Appendix 4, Figure 1. The values are much higher than estimates for clays soils in Australia, as expected. The values however are of about the range of values expected for loamy soils. It is noted that for very high water tables the capillary rise potential is much higher than the maximum evaporation which may be expected from a bare soil. The values from the equations of Ref.2 therefore need to be adjusted for factors which limit capillary rise. One of such factors is the moisture content of the surface layer, or the root zone where it is abstracted.

Report Ref.1 does not refer to a reduction in CR at the dry end of soil moisture, or at the wet end near field capacity. It is understood this a complex matter, because apart from moisture content the reduction is dependent on the rate of abstraction at the surface level (crop evaporation). The optimal CR for a specific crop ET rate occurs when the soil is moist in the mid range between field capacity and dry. At the wet end there is no suction gradient, hence CR must be zero. At the dry end the unsaturated hydraulic conductivity is very low ([24]). Figure 2 of Appendix 4 shows the approximate shape of the curve showing capillary rise as a proportion of its maximum.

Field efficiency is often expressed as a proportion of field diversions, as in Ref1. However, in practice it may not work this way. Farmers irrigate on rotation, or when the soil moisture deficit is say 50mm below field capacity (on average). They then irrigate, probably applying more water than what is needed to just replenish this soil moisture deficit. Observation of irrigation practices in the Kongque area shows that people may actually bring the moisture level in the soil to saturation point in the root zone. After irrigation the excess moisture above field capacity will drain to the water table, which will rise. When the water table is already high the proportion of percolation will be less.

It is not possible to analyse alternative effects of irrigation practices in a monthly time step model. It is possible however to do this in a daily time step model. The stand-alone model referred to in Appendix 4. May be used to examine these aspects.

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[24] With decreasing moisture content the unsaturated hydraulic conductivity decreases faster than the rate by which the gradient increases. Overall therefore there is a decrease in upward flux.

APPENDIX 3.

WATER AND SALT BALANCE MODEL

The algorithms were checked and generally no deficiencies were found. The basic construction appears sound. The main issues to be discussed relate to the way surface drainage volumes are calculated and the salt balance equations.

Surface Drainage

Surface drainage DGW is generated as a surplus derived in the groundwater balance, only occurring when crop demand is satisfied. DRAIN is calculated from FDIV and CSUP, a proportion factor and FEFF. CSUP is dependent on FLII and GIR. Since FLII includes FEFF already, and it is hard to see how capillary rise affects surface drainage, the use of the algorithm for DRAIN is questioned. Perhaps it is better to simply use:

- FDIV = FLI + FLII
- FLI = FLIA + FLIG,
- Set FLIG as proportion of FDIV
- Set DRAIN as proportion of FDIV

The proportions used would be part of the calibration process, and are also determined by experience, e.g. Drainage = 5% of FDI, FLIG = 20% of FDIV for sandy soils, 5% for clay soils. These factors may be varied with seasons if necessary.

An understanding of the the methods of irrigation and the likelyhood of some run-off occurring after each irrigation are critical for the way these equations are set-up. If there is uncertainty the simplest method is probably the best.

Salt Balance

Reservoirs

The equation at page 25 is suggested to be only approximate. Reservoirs probably are not a large component in the salt balance (small total area), but perhaps the equation to calculate reservoir salinity should be improved or simplified, e.g.

$C_{new} = (1+ SEV/((RESVOL_0+RESVOL_1)/2+(SRI+SRO)/2) * C_{in}$

Rivers

Appears OK

Saturated Groundwater Reservoir No suggestions at this stage

Irrigated Fields.

Equations for C_{sm} top of page 28 appear too complicated.

$z= SALIN - Q_0*C_{sm} = SALIN - SALOUT = dS/dt = VOL * dC_{sm}/dt$?

then $C_{sm} = -VOL/Q_0 * dC_{sm}/dt + SALIN/Q_0$

If this is correct the solutions may also be correct.

Qi should be taken as FDIV – Drainage.*

Not Irrigated Unsaturated Fields

No comment.

Lakes

$C_{lakenew}$ = (VOL * C_{lake} + SALIN +SALOUT)/(VOL – E_{lake}).

The evaporation factor should be added. Is probably already in the model, but not shown in Ref 1.

APPENDIX 4

STAND-ALONE DAILY ROOT ZONE MODEL

Introduction.

A daily time step irrigation module with groundwater linkages has the advantage of being better able to reflect the water and salt movement processes. It is realised that a perfect model is near impossible to construct, after all, climatic conditions vary, crop variety choices, irrigation management practices, fertiliser use, soil variation, day and night temperatures, etc. vary, and there will be large spatial variation in infiltration and capillary rise rates. Even a process model using daily time steps therefore is a compromise. Nevertheless, it is probable that a daily time step process model allows for a better interpretation, hence a better insight regarding the fate of salts and water.

Conceptual

The process model discussed here has been prepared over a short period, and may be further improved. The conceptual diagram is shown at Figure 1.

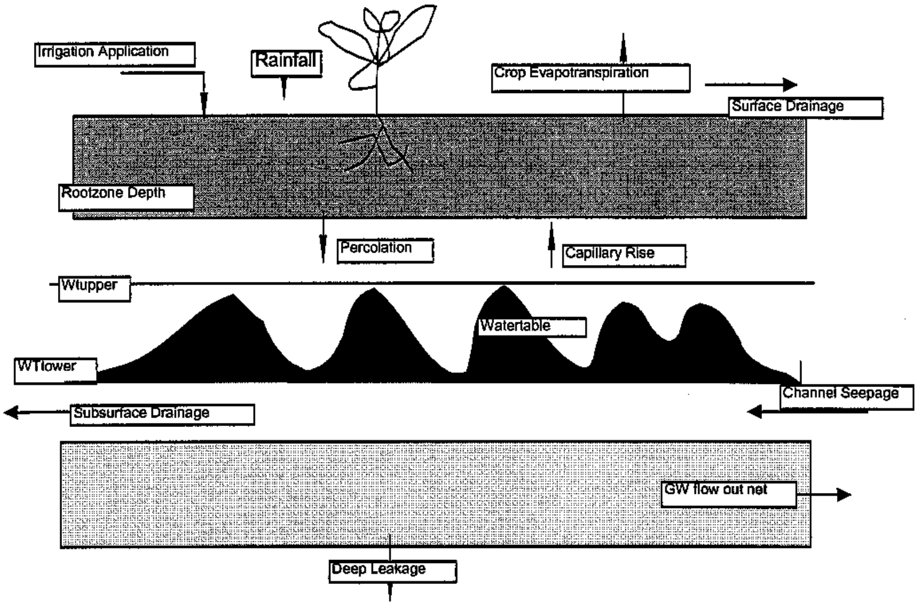

Figure 1: Conceptual diagram of daily time step model for Yangi area.

This model is somewhat different than the model of the Yangi groundwater model, as described. Figure 1 shows the water table aquifer, into which channel seepage occurs and sub-surface drainage abstracts water. The deep aquifer is not shown, but the leakage term at the bottom refers to the deeper aquifer as a source or sink in the irrigation module.

Three layers are perceived, the rootzone layer, the shallow water table zone, and the deep groundwater (of the shallow aquifer). Each of these has its own salt content and moisture store. The depth of root zone may be selected dependent on the main crop types grown, for instance one metre in depth. The water table zone is from the bottom of the root zone to the bottom of the general variation in water table depth. This may be two or three metres. The deeper ground water is always saturated and has a salinity equal to the aquifer if leakage is upwards, and equal to the water table layer if leakage is downwards (25).

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[25] This latter aspect is not yet fully developed for this model.

After each time step it is assumed that there is full mixing of salts within each layer. This assumption of course is flawed, but there is little alternative unless a different, more complex, process model is developed, which is beyond the scope of this review, and perhaps not useful. The assumption made is necessary to assign salinity values to the percolation, the capillary rise, the sub-surface-drainage factors at each time step.

Processes

Soil moisture varies between field capacity and a dry point, which may be selected at for instance 50mm less. Crop (or fallow) evaporation based on Penman ET and crop coefficients cause the drying out and the soil moisture deficit change. Irrigation is applied at the dry end of this spectrum, and the volume of application is to replenish to saturation for the whole of the root zone. Percolation during the next day is based on the excess of saturation moisture content over field capacity. The percolation volume may be modified in the model based on the perceived field irrigation efficiency.

Capillary rise is based on the curves of the maximum values as per the Yangi area ground water model. Figure 2 shows the curves for various soils.

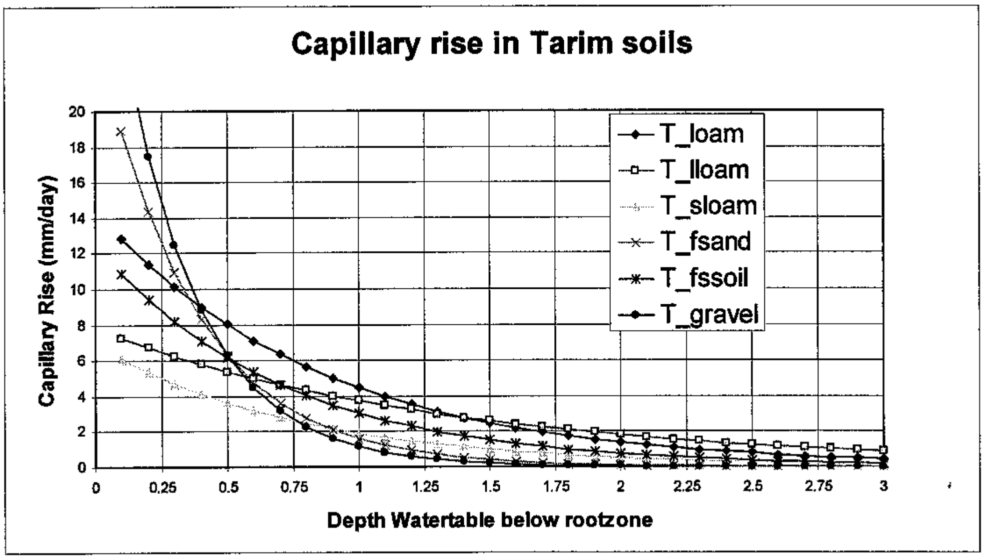

Figure 2: Maximum capillary rise rates for Tarim basin soils.

The values of Figure 2 are modified in the daily model for soil moisture content. First of all, the capillary rise, if higher than evapotranspiration will increase soil moisture faster than the depletion rate. When the soil gets wet due to this process or irrigation, then capillary rise will reduce. Capillary rise is subject to soil moisture potential gradients (wet to dry), at the wet end of soil moisture the gradient is zero. At the dry end of the range of soil moisture capillary rise will also reduce, because with increasing dryness the unsaturated hydraulic conductivity of soils decreases faster than the moisture potential increases. Since flow is according to Darcy's law, the flow will reduce in these conditions.

The effect of the above is that the capillary rise is being multiplied by a proportional factor as shown at Figure 3.

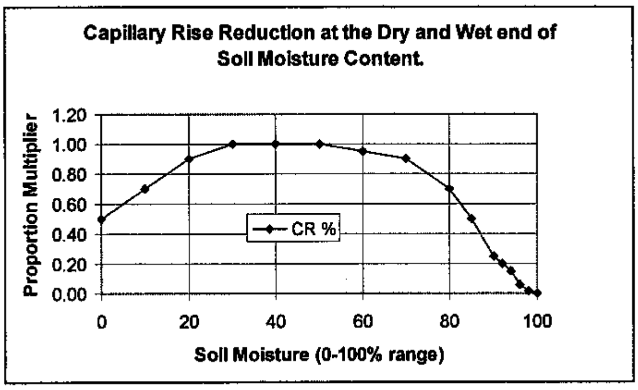

Figure 3. Proportion of maximum capillary rise used in model based on soil moisture content.

Capillary rise is calculated from the above, using as reference height of upward flux the distance from half the depth of the root zone to the depth to the watertable for that day ([26])

The salinity is expressed as the salinity in grams/litre (g/L) for the water table zone and for the rootzone. The reference soil moisture content is based on the volume of moisture stored in each of these two layers. The former of these should be converted to field capacity or saturation extract to allow comparison of the salinity against crop tolerance values (see Appendix 1).

Initial values for soil moisture, depth to water table and soil salinities are assumed. Several other input values have to be determined, see sections on crops and soils below. The input values on a daily basis are determined, the soil moisture content and salinity (salt content) of the root-zone and water table are determined. After this the various values of irrigation, percolation, capillary rise are added / subtracted to the soil moisture store the water table store. After this the values for upward leakage, sub-surface drainage, and channel leakage are determined (see Appendix 2), and also added to the water table store.

Values of salinity in the various layers are based on the end of the previous day values, allowing the calculation of the transfer of salts between the different layers. The additions are added or subtracted from the salt store and the new values determined.

The value for water table moisture store is converted to a depth to watertable value.

Data Compilation

The model described above in in EXCEL 5. Three main input sheets exist, climate, crop and soil.

Climate Data Sheet:

The "climate" sheet contains monthly values for ET (Penman) and Rainfall ([27])

Crop Data Sheet:

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[26] At Appendix 2 it was already observed that this method stil only is an approximation, because the effect of variable crop evaporation is not included in this model.

[27] The current version uses open water surface evporation divided by 0.7, by lack of ET data in the groundwater model report (Ref 2).

This sheet uses the climatic data and adds the crop factors for several crops, allowing calculation of crop water demand. For non cropping seasons a low 0.1-0.2 value is entered for the crop factors to represent bare soil surface soil moisture loss. The depth of the root zone of the crop at each month are also shown (as a proportion of the maximum depth (see "soil" sheet). The "crop" sheet allows the use of crops over a four year period, and alows a choice of the cropping sequence. The ET and crop ET values of the four crops selected in the sequence selected transferred to the right hand side of the sheet. These values are accessed by the main "input" sheet (see below).

Soil Data Sheet:

The 13 stratigraphical combinations of the ground water model report (Ref.2) were used as a basis for values of transmissivity, semi-confined layer conductance, soil porosity, drainable porosity, and thickness of strata. Many other values were required for the daily model, as follows:

- Depth rootzone, depth water table (upper and lower).
- Irrigation water salinity
- Soil moisture deficit as a trigger for when irrigation commences.
- Initial values for moisture content and salinity of root zone and water table layer, water table depth, salinity of deep groundwater.
- Minimum soil moisture content value in model.
- Field capacity, saturated moisture content, drainable porosity.
- Bulk density (for conversion of salinity to saturation extract equivalent).
- Capillary rise curve to be selected for soil in question.
- Proportion of irrigation water going to surface drainage.
- Surface drainage water salinity as a proportion of irrigation water salinity (e.g 125%).
- Drain spacing, soil permeability, depth of drains.
- Conductance aquitard, pressure deeper aquifer.
- Groundwater flow out of the area in question (assumed zero, except for rice).
- Supply channel spacing, soil permeability, level of water in canals relative to soil surface.

These values were determined for each of the 13 soil combinations to aenable testing of the model. It is obvious the values will require updating by XinJiang University Staff for further appraisal.

The top cell of the third column of the "soil" sheet allows a simple choice of one of the soil combinations and the data values described above will be copied into a single column.

Data Processing.

The data from the crop sheet and the data sheets are linked into fields of the "Input" sheet. The crop monthly data are converted into daily values where appropriate.

The "input" sheet also contains the capillary rise reduction values, and the assessment of additional drainage should the water table rise above the soil surface.

The "model" sheet exclusively uses data from the "input" sheet.

Results.

The "model" sheet contains over 1400 lines for daily processing. The monthly values are compiled as an average or an end of month value in the "out" sheet. Further summarising to annual values occurs in the "sum" sheet. The monthly results are graphically presented in five sheets for the four year period:

1. The "sms" sheet shows the variation in soil moisture values.
2. The "wt" sheet shows the water table behaviour.
3. The "ss" sheet show the soil salinity for the rootzone and the water table zones.
4. The "irr" sheet shows the monthly crop evaporation, irrigation volumes, surface drainage, and capillary rise.

5. The “flux” sheet shows the fluxes of channel seepage, sub-surface drainage, upward leakage and percolation to the water table.

The model allows for a rapid examination of the results for a specific crop and soil combination. Annual totals may be examined from the “sum” sheet.

It is likely that many outputs are not highly credible at this stage. It is possible to modify the input value of parameters in the “soil” or the “crop” sheets. It is also possible to use the “cal” sheet (calibration) to change some parameters, for instance the aquitard conductance value and soil permeability for sub-surface drainage volumes.

Further Work.

The model requires improvement in some areas, some algorithms may be improved.

The aspect of rice growing in the Yangi area has not yet been incorporated. This may be achieved by cancelling the irrigation algorithms and substituting a water table at the soil surface. This will provide the change in leakage to the deeper aquifer, but unfortunately it is not possible to model the lateral groundwater flow in the surface aquifer, which may be very significant ([28])

Following the examination of processes and results of the daily EXCEL model it may be considered to prepare FORTRAN subroutines reflecting the above. If suitable modifications are the result of these actions, the objective of this work would be achieved.

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[28] The Yangi area groundwater model does not estimate the leaching effect of rice growing correctly either, because the shallow zone is assumed to have zero horizontal permeability.