SATELLITE OBSERVATIONS OF INTERNATIONAL RIVER BASINS FOR ALL

W.G.M. Bastiaanssen*/ and S.A. Prathapar****

* International Water Management Institute (IWMI), P.O. Box 2075, Colombo, Sri Lanka, W.Bastiaanssen@cgiar.org
** International Institute for Aerspace Survey and Earth Sciences, P.O. Box 6, 7500 AA, Enschede, The Netherlands, Bastiaanssen@itc.nl
*** International Water Management Institute (IWMI), 12 km Multan Rd, Lahore, Pakistan, S.Prathapar@cgiar.org

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Abstract

A river basin is the prime land unit for collection and depletion of water, ultimately leading to rich and attractive environments to live in, having food security, industrial production and socio-economic development. Water flows across and underneath, international boundaries and sustains entire agro-ecosystems, whose boundaries do not conform to the political lines we human have drawn on maps. Understanding of the resources management may lead to development and revision of water treaties between states, and prevent potential conflicts and resolve disagreements. Provision of objective information to facilitate negotiations between various fellow states requires a tool, which can monitor spatial and temporal changes in water demand and water use over vast rural areas. This requirement can be met with low resolution satellites having daily overpasses. Some examples of technically matured possibilities are given. It is concluded that these opportunities are disregarded and not applied, most probably because it requires an interdisciplinary approach between remote sensing specialists and water resources managers. Remote sensing information, being available to all parties can help creating consensus on the basin conditions – from upstream to the downstream end. It is believed that subjective information and database building is a stimulus for international collaboration between fellow states sharing an international river basin.

1 Introduction

Every year, the world's population increases by 80-85 million inhabitants at a rate of 1.5 %.
In the 20th century the world population tripled – while water use multiplied sixfold. According to the medium projection of the United Nations, the world population will reach eight billion by 2025. Some developing countries have a projected annual population growth rate of 3 % - their population will double in less than 25 years ! Besides more mouths to feed, changing tastes and improving diets increase the food and water demands. As fresh water resources are limited, the question arises of whether there is sufficient water per capita available in the 21st century ? By comparing water demand for food, the environment, industries and domestic use with the water supply available from precipitation, snowmelt and aquifers, it is predicted that more than 20 developing countries will experience chronic and physical water shortage in 2025 (Anonymous, 2000a). There is physical shortage, but also due to poor management. Or in the words of the World Water Council: "Todays water crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people and the environment suffer badly" (Cosgrove and Rijsberman, 2000).

At the moment, one billion people are without access to safe drinking water and three billion have no access to sanitary services. A further 65 countries will be facing economic water scarcity by the year 2025 – requiring substantial investments in water resources development to meet future demands. Historically people settle in river basins, where water is available from runoff, snowmelt, sometimes accomplished by groundwater inflow from neighbouring areas. Most of the world's largest cities are built on river embankments and withdraw and discharge their water on the river. In these river systems, the environment is put at risk by extracting ever-greater quantities of water for food production. But also the agricultural production is under threat by the increasing competition with the domestic and industrial sectors. The agricultural sector has to produce more food from less water resources, and this is a challenge for them (Merrey and Perry, 1999). Food is required to feed the rapidly growing population, and good management should prevent famine, alleviate hunger, halt environmental degradation and stimulate economic growth.

Water flows across international boundaries, whose boundaries do not conform to the political lines we human have drawn on maps. Nearly half the world is situated in 250 to 300 international river basins. Acriminous disputes over water are bound to affect the good relations between countries, even if they do not lead to outright war and armed conflict. There is a multitude of possible approaches to regional cooperation (Anonymous, 2000b):

- Cooperation as allocation: agreement on water allocation for sharing purposes
- Cooperation as salvation: avoiding absolute disasters in the form of violent conflicts or environmental destruction
- Cooperation among stakeholders: communication and trust between different interest groups

Absence of international collaboration can be a source of tension and strife, and this should be prevented by a shared water resources strategy. An integrated holistic approach to international water courses is needed, in which the basin is accepted as the logical unit of operation. Pertaining to international river basins, no government should utilize the resources of a shared watercourse in such a way that fellow basin states are subsequently unable to achieve sufficient access required for a standard living (Sokolov, 1999). A multi-sectoral, integrated system, complemented by information sharing, transparency and wide participation is therefore best suited to encompass all these elements.

All users are hydrologically linked in a river basin. Upstream water use has immediate effect on the downstream users, although this distance may be thousands of kilometers apart and be located in another country. Land and water use planning in one part of the basin is paramount for the users in another part of the basin (e.g. Bos, 1996). Flow commitments by means of water treaties between states are necessary for sharing resources and utilizing the resources better. Floods pose one of the most widely distributed natural risks to life. Between 1973 and 1997, an average of 66 million people a year suffer flood damage (Anonymous, 1999). Increasing water storage, retaining flood waters until the moment needed for human use, remains an almost unavoidable element of water resources management in arid zones. Developing additional water supplies by upstream water storage can have dramatic consequences for downstream water users and their environment. Upstream riparians should not deprive downstream riparians of access in terms of quantity and quality. Also environmentally endorsed activities can have deprives: Stimulating agro-forestry to enhance biodiversity and reduce soil erosion can lead to extermination of flora and fauna further downstream. Integrated water resources management in the context of river basins provides an understanding of inter-sector competition of scarce water supplies, water quality, the significance of water recycling, multiple uses of water and links all riparians. A practical consequence of the river basin management paradigm is that growing 1 ha of wheat requires a volume of water equivalent to supplying 250 citizens the whole year round with water for drinking and bathing. Thus under severe water scarce conditions, it is wiser to import food and preserve water for human consumption.

The absence of effective international and regional agreements and institutions for water sharing and basin management, will make for a world scenario in which conflicts over water are more likely.

International cooperation should focus on exchanging jointly gathered data. This paper addresses the potential role of remotely obtained geo-information of river basins, shows some examples and the type of information what can be assesses, and discusses opportunities to utilize existing international space programs and databases better.

2 Need for an accounting and monitoring system

The irrigation sector is by environmentalists often regarded as inefficient, with huge amounts of water being wasted. This is somewhat short-visioned, as leaking and percolating water supplements aquifers and often or flow back to the lower laying river valley. It is ultimately somebody's else water resource. Water in river basins is recycled both naturally and man-induced and this decreases the water losses (Keller and Keller, 1995). Recapturing irrigation losses through groundwater extraction of industries or by means of seepage towards wetlands are examples of depleting left overs of irrigation water diversions. The river should be seen as a central, unifying feature at the heart of a region, with the capacity to recycle water. Consequently, linkages between sources, uses and re-uses must thus be fully understood to appraise system losses, efficiency and possibilities of water savings (Perry, 1999). Saving irrigation water can thus be detrimental for industries, who rely on sufficient groundwater quantities.

Proper water accounts support the appraisal of room for improving the productivity of water in a river basin. Water accounting is a basically new dimension to the water balance as it describes by whom the water is used and provides insights how water can be made more productive and economically rational (Molden and Sakthivadivel, 1999). Water accounting addresses issues such as water storage, flow committed to neighboring areas, water consumed by environments, water consumed by native vegetation, crop consumptive use leading to food production, depletion due to industrial producers and non-beneficial use of water such as soil evaporation. The depletion of water in a river basin is according to water accounting diverted into processes and non-processes. An example is given in Fig. 1 based on the hydrological year 1998 of a drainage basin in Kenya. It shows that most water is consumed by native vegetation and natural forests. The total amount of depleted water is a large fraction of the gross inflow, which implies that little water flows out from this basin. Most water is however depleted by native vegetation such as low productive rangeland and bushland (606 million m^3). Despite the inhabitants view on water resources use, most crop consumptive use occurs in the rainfed agricultural fields being located uphill far away from the villages. Rainfed crops consume with 517 million m^3 seven times more water than the irrigated crops in the vicinity of the lake. The irrigated farms create also substantial employment and is good for Kenya's export. This demonstrates the advantages of thinking in the basin context and the need of accounts to understand what happens.

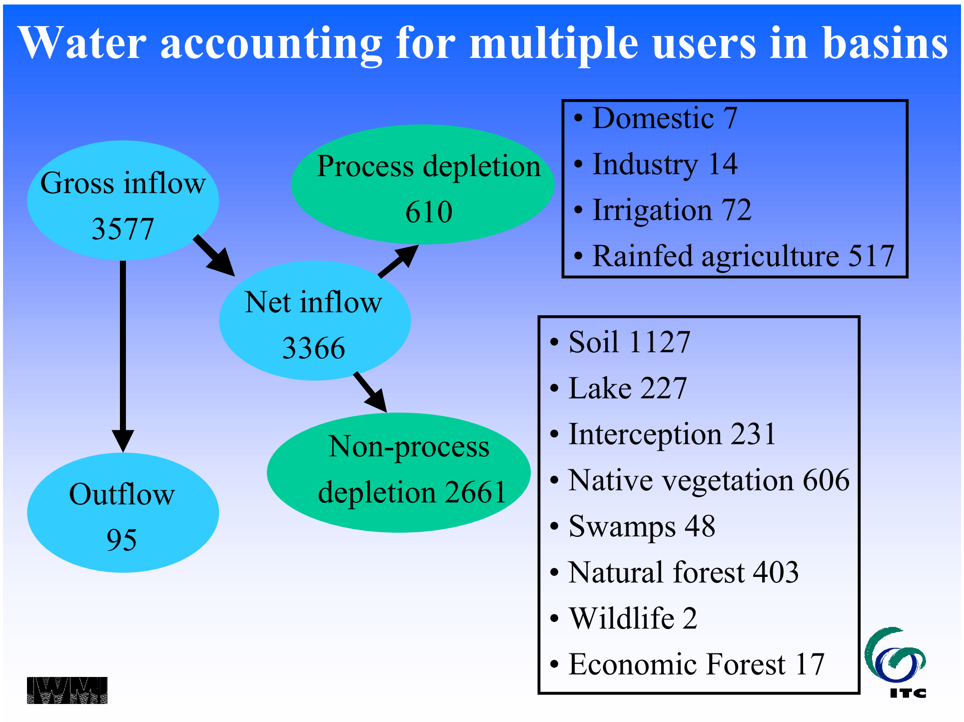

Fig. 1: Water accounts for the Lake Naivasha drainage basin during 1998, Kenya. The numbers present million m^3 yr^{-1} *(data withdrawn from Salah, 1999)*

Conflict prevention is perhaps, the most important water management strategy for the 21st century. A regional cooperation on water issues and comparison between fellow states in a basin requires a standardized description of the water flows and the resulting processing emerging from that. One possible way of promoting a climate of confidence and favourable political will is by database building and deriving the water accounts subsequently from that. It must be admitted that nobody has reliable data related to water resources conditions, as data gathering and definition procedures greatly differ. We are plagued by insufficient data on water resources, just as we are plagued by insufficient water (Bastiaanssen, 1999). Satellite measurements can therefore have a significant contribution, and this aspect is grossly underestimated.

3 Geo-information for all stakeholders

3.1 Remote sensing and GIS

Trust and faith in international river basin water resources management increases if rainfall, diverted water, soil moisture, crop evapotranspiration and plant growth data is collected at a range of scales, is adequate, available and accessible. It must be admitted that in a relatively short time span, hydrologists cannot diagnose the water accounts at the regional scale if hydrological data is improper or incomplete. It requires several months or even years by professionals to thoroughly quantify or model the hydrological processes and cycles in a river basin using other parties data. Satellite data can form an attractive alternative to numerical models.

Satellites provide objective data for database building, which is politically neutral and cannot be manipulated. Satellite measurements reflect the land surface features and the observable landscape patterns culminated from socio-economical development, prevailing jurisdiction, agricultural practices, hydrological processes and irrigation management, apart from its original geological formation processes. Because of being direct measurements, satellite observations are often more reliable than secondary data. For instance, the irrigated area in the Gediz River Basin in Western

Turkey appeared from the satellite images to be 60% larger than from the secondary data collected from governmental statistics. Another example of dubious secondary data is from Pakistan, where different soil salinity surveys resulted in more than 500 % between the lowest and the highest estimate of soil salinity occurrence in Pakistan. It is obvious that if such type of secondary data is used in establishing intra-basin water cooperations, disputes and conflicts can potentially worsen and trust will fade away.

The spatial resolutions of satellites can be divided roughly into 3 categories. Low resolution satellites have a spatial resolution of typical 1 km, and this category is most promising for surveying large basins. More candidate sensors will be launched in the future, and a summary is presented in Table 1. High resolution satellites have a spatial resolution in the range between 20 to 30 m. They give a high degree of spatial detail, but their return period is with 15 to 25 days not suitable for concurrent monitoring. Cloud formation can wipe out acquisitions easily, so that data is not acquired for elongated periods. More recently, there is a third category of earth observing satellites that is operational with a spatial resolution of 1 to 5 m. These fleet of satellites is particular useful for sensing cartographical features and civil works.

Satellite	Radiometer	Spatial resolution	Temporal resolution	Total bands	Spectral region
NOAA	AVHRR	1.1 km	0.5 days	5	VIS, NIR, TIR
Envisat	AATSR	1.0 km	1 day	18	VIR, NIR, TIR
Envisat	MERIS	1.0 km	3 days	15	VIS, NIR
TERRA	MODIS	250 m to 1.0 km	1 to 2 days	36	VIS, NIR, TIR

Table 1: Operational low resolution satellites and radiometers suitable for monitoring hydrological processes in vast international river basins

The public character of satellite data entitles different user categories to use this data. With raw satellite data on the Internet, states are no longer be able to conceal field conditions to their fellow basin states. Several space agencies are now opening international and freely accessible databases with raw or first order processes satellite images. Data from an international fleet of sensors can be found in the Earth Observing System Data and Information System (EOSDIS). Eight Data Active Archive Centres (DAAC's) representing a wide range of Earth science disciplines are operational under NASA to process, archive and distribute EOSDIS data. The Earth Resources Observation System (EROS) Data Center of the USGS provides in addition access to land processes data from both satellite and aircraft platforms. A WWW interface enables you to search for, browse and order earth science data. It is a new policy to keep prices of images low, so that satellite information becomes everybody's business. Some examples of internationally opened satellite databases can be found at http://www.saa.noaa.gov, http://daac.gsfc.nasa.gov or http://modis@nsidcdaac, to mention a few. There are no restrictions on the use, reprocessing or redistribution of the satellite data made available through the USGS and NASA. Some satellite data are entirely free, for others preprocessing costs have to be covered from purchases.

This opens complete new opportunities to study the hydrological process, water resources depletion, food security and environmental development in international river basins. It opens a new protocol where central governmental bodies and internationally controlling agencies get united information. Remotely sensed information has a public domain status, and everybody listed in Fig. 2 can have access to raw satellite information. Federal Governments and the UN can inspect land and water resources management issues, either by hiring their own experts or by involving commercial consultants.

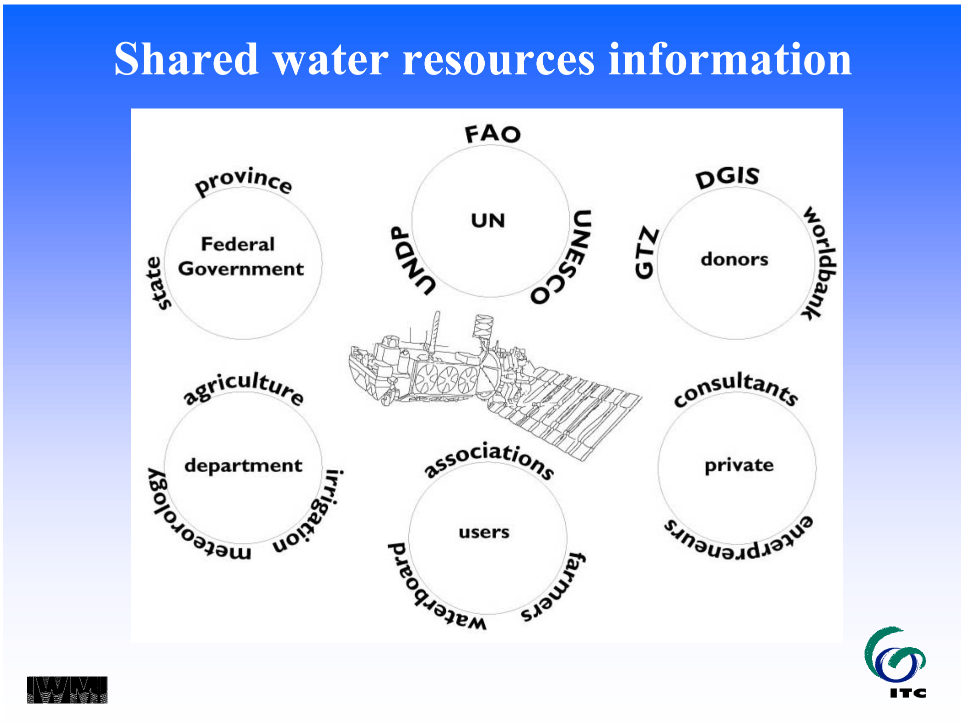

Fig 2: Access to shared water resources information from space by various actors resulting in new control mechanisms in management

The scientific progress of satellite interpretations has undergone major improvements in the last 10 years. Conversion algorithms between the spectral radiances at the one hand and bio-phyiscal or hydrological parameters at the other hand have been improved. Some review of progress can be found in (Engman and Gurney, 1991; Kite and Pietroni, 1996; Rango and Shalaby, 1998; Schultz and Engman, 2000; Bastiaanssen et al, 2000). Basic research is elementary for improving the accuracy of estimation procedures, because none of the surface features summarized in Table 2 can be directly measured. Remote sensing scientists have generally not grasped the need to investigate river basin processes and dedicated more efforts to climatology and ecology (e.g. Nemani et al., 1996). Driving the research community is an important asset for the future.

Discipline	Application
Hydrology	Snow cover, precipitation, soil moisture, evapotranspiration
Agriculture	Irrigated area, rainfed area, crop identification, biomass growth, crop yield, irrigation performance
Environment	Forest area, wetlands, rangelands, waterlogging, salinization, water quality
Geography	Digital elevation, land slope, land aspects, land cover, land use

Table 2: Satellite measurements for possible applications in national and international river basins

It should be recognized that lots of database building has been realized during the last 10 years. Several public domain databases on climate, river runoff, land cover and elevation have been established and are continuously updated. The US Geological Survey has prepared a digital elevation map of the world with a 1 km spatial resolution, GTOPO30, which is available at the world wide web. The global land cover map from Eidenshink and Faundeen (1998) has a global 1 km grid. Examples of finer resolution land cover databases are IGBP-DIS global land cover data set Discover (Loveland and Belward, 1997), Corine, Pelcom, Africover (FAO) and the Asian Association on Remote Sensing AARS-Global Land Cover Data Set (Chiba University). Discover only recognizes cropland and no further breakdown in crops or irrigated agriculture is made as it aims at support global change modelling. Corine, Africover and AARS are more suited for planning of agricultural development.

The examples shown in Section 3.2 describe cases of remote sensing studies in large river basins. None of these cases cover an international water course, but there is technically no difference in determining river basin parameters from space between national or international river basins. The satellite data of the examples are all taken from the National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA-AVHRR). This satellite has a swath width of 2800 km, has a polar orbit and revisits every area twice during daylight hours. There are two satellites operational, NOAA14 and NOAA15. Future satellite systems with equivalent sensors such as demonstrated in Table 1 could be used for these type of applications.

3.2 Selected examples of quantifying river basin processes using satellite measurements with a 1 km spatial resolution

Case 1: Snowmelt and reservoir inflow, Canada

Kite (1995) developed a distributed watershed model dedicated to make maximum use of remotely sensed data. This distributed hydrological model SLURP uses digital elevation data from public domain databases accomplished with NOAA-AVHRR images to divide a large watershed into simulation units with different land cover classes. The runoff from each simulation unit is routed down the watershed and aggregated to simulate streamflow. Daily NOAA-AVHRR data is used to classify cloud cover, snow extent and leaf area index. The land cover classes (water, deciduous trees, coniferous trees, barren land, perennial snow/ice) could also be successfully obtained from NOAA-AVHRR images. Day-to-day simulations of surface runoff into the reservoir could be calculated and used for reservoir operations of the upper Columbia watershed. This information is important for water availability and water diversion to irrigation systems and hydropower generation.

Case 2: Soil moisture in space and time, Iran

Soil moisture is an indication of water stored in the unsaturated zone. Under arid conditions, soil moisture patterns are a direction indication of the irrigation water distribution or natural seepage zones holding the soil wet. The Zayandeh Rud basin in Central Iran is a basin hosting millions of people – the historic city of Esfahan is Iran second largest city and located in the basin – and essential for Iran's national food production through water diversions. Access to water is equivalent to possibilities for agriculture and establishment of socio-economic development. The soil moisture patterns show the inter-annual diversions of irrigation water. Fig. 3A shows the soil moisture fields during May when winter crops are almost at the end of their growing period, and Fig. 3B expresses the conditions in August when summer crops are fully emerged. Fig. 3 demonstrates that the lower part of the basin receives less water and that a minor portion of the basin has access to huge and unlimited water amounts; a soil moisture content of 0.40 cm^3 cm^{-3} throughout the season reveals that the soils are at field capacity or even wetter. Fig. 3 has been determined without any ground information. If this basin would have been international, a trained person from an international organization and knowledgeable on GIS and remote sensing could have prepared this map.

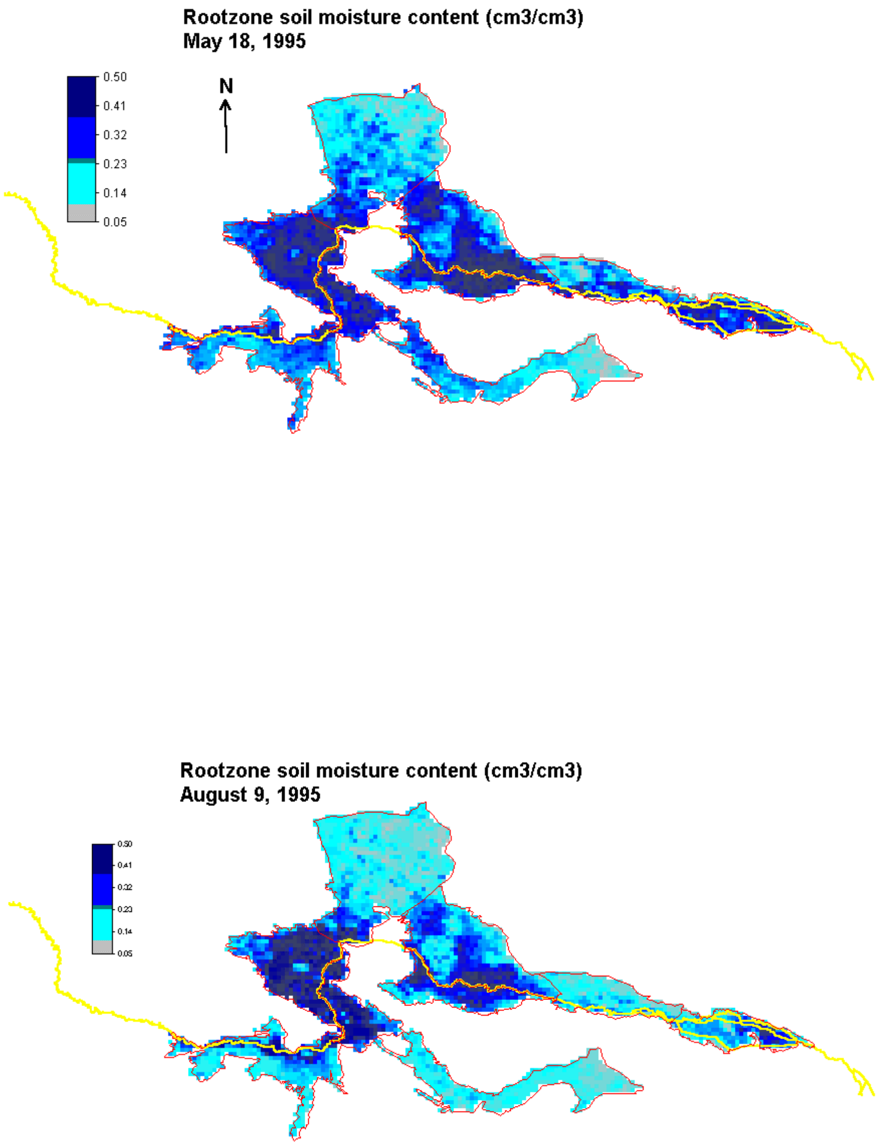

Fig. 3: Soil moisture in space and time across the irrigated Zayandeh Rud river basin in Central Iran. Part A covers the situation for winter crops (May 1995) at the end of the growing season and Part B shows the conditions for summer crops (August 1995)

Case 3: Evapotranspiration patterns in the Indus Basin, Pakistan

The actual rate of evapotranspiration is difficult to infer from standard weather data, but is relevant for water consumption of agriculture, forests, swamps, wetlands and other types of land cover. This information is helpful in assessing other components of the water balance, such as groundwater recharge and runoff. Spatial and temporal variation of actual evapotranspiration across all 44 irrigation command areas in the Indus Basin were determined using satellite images (Bastiaanssen et al., 1999). The irrigation sector is often criticised for insufficient use of water resources. By comparing water diversions to consumptive use, estimates of water losses can be made.

Irrigation water supply in Pakistan is based on equal access to all farmers. Without doubt, such novel aspiration is difficult to achieve, in any irrigation scheme in the world. Farmer communities often claim that they are not receiving the volume of water they are entitled to. The same discussion on water volumes occurs between fellow states sharing an international water course. Fig. 4 shows that the head end villages in the South-eastern Punjab receive systematically more water – the actual evapotranspiration is 3 to 4 mm d^{-1} at the end of the winter season - than the tail end farmers with an evapotranspiration of 2 mm d^{-1} (Alexandridris et al, 1999). Not only on one moment during a satellite flyover, but this trend was observed to hold for the entire irrigation season. The communities settling in the tail end can make a strong case now to their government if the images are given to them; they are right to complain. It is sour though, that academists working from advanced centers can see that they are shortened, and farmer communities don't know that this information is readily available.

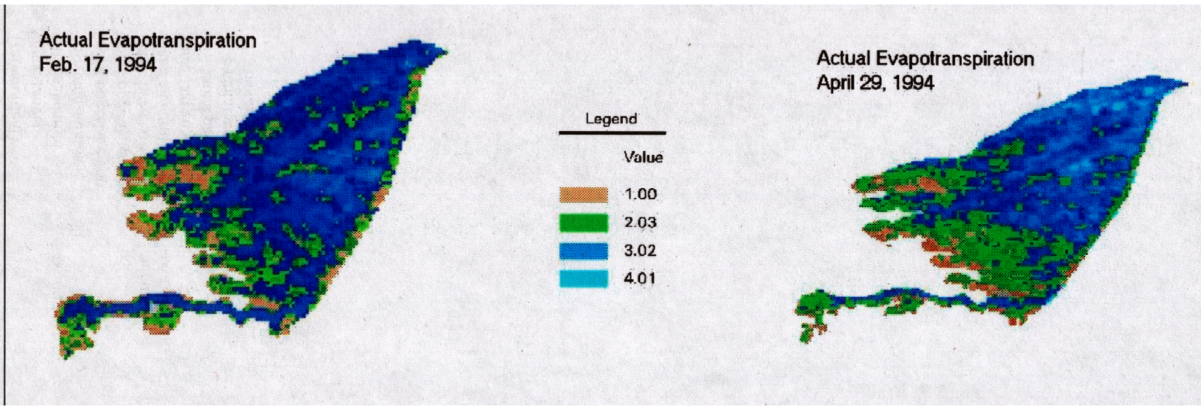

Fig. 4: Consumptive use along distributaries in South eastern Punjab showing inequity access to diverted water volumes

Case 4: Agricultural productivity in the Ganges Basin, India

River basins with fertile alluvial soils are suitable for crop production and nations have to eat from basins. For reasons of food security, State and Federal governments need to be timely informed on the crop growth status. This is essential for food distribution, storage arrangement and in case of shortage, for timely purchasing food on the world market before prices rise up. A significant international food trade is expected to emerge in the 21st century. A crop growth monitoring system can help policy makers estimating the yields and understand whether trade with basin counterparts is necessary. It also provides interesting insights in yield gaps arising in the same agro-ecological production zone. The yield gap tells the possibilities of increased food production, provided the water is available.

The wheat yield in part of the Ganges river basin in Nortwestern India was discussed. The yields in the state of Haryana and Uttar Pradesh were different, in favour of Haryana The explanatory factors have to be explored, and factors such as different water duties, geology, soil types and farm management are likely to play a role. Systematically, the highest yields occur close to the source of water at the foothills of the Himalya. But yields are also systematically higher at the left and right bank of the Yamuna river North of New Delhi.

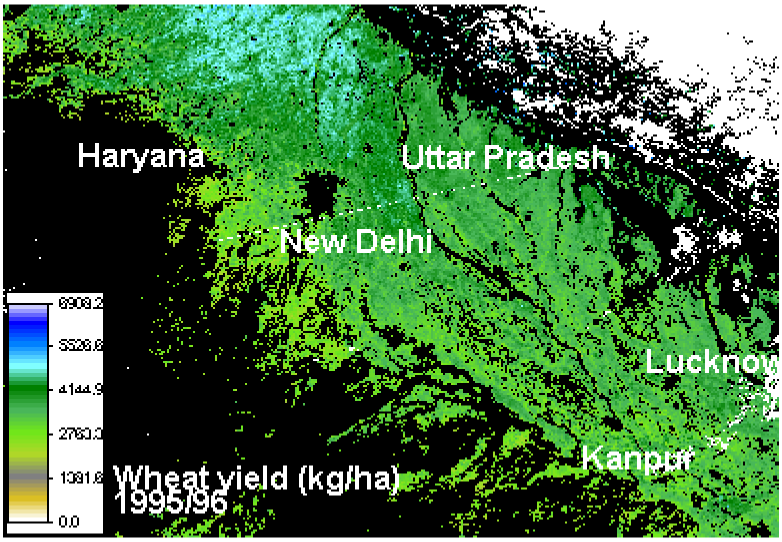

Fig. 5: Wheat yield distributions over the states of Haryana and Uttar Pradesh

4 Suggested applications of geo-information in internationally shared river basins

The high cost of space research makes it imperative that the nations of the world pool their scientific, technological, and other forms of resources for common benefit. The space programs of the US, EU and Japan have some joint activities. Dedicated working groups are established to promote the use of data originating from a specific sensor. MODLAND is such an endeavour for the storage and processing of land cover and land surface related parameters from MODIS (Running et al., 1994).

Remote sensing can also be promoted thematically such as for the hydrological branch. The International Association for Hydrological Sciences (IAHS) has a working group on International Commission on Remote Sensing (ICRS) and the American Society of Photogrammetry and Remote Sensing (APRS) has a working group on Water Information Management Systems. This is believed to be more effective and exciting than exchange of experiences through remote sensing communities such as IEEE, European Association for Remote Sensing and Land (EARSEL) and International Society of Photogrammetry and Remote Sensing (ISPRS). Water resources managers don't know about the existence of EARSEL and ISPRS.

A working group composed of international scientists who discuss remote sensing algorithms necessary for river basin management, test these algorithms in joint field experiments and process satellite data in a routine way leading to database building. Local experts and consultants can then apply the technology to specific basins after having received training. In case of serious disputes between basin member states, the international working group can assist with a third and neutral opinion. It is believed that discussing information facts, aids the negotiation and collaboration process between fellow states. Several case studies have been conducted by the International Water Management Institute where experts used public domain databases complemented with satellite measurements to make hydrological analysis of basins without visiting them (e.g. Kite and Droogers, 1999). Although it is not encouraged to execute desk studies, it demonstrates technically new opportunities to analyze the processes in international river basins when data is made accessible to everybody.

The management of international water has implications at the local, regional and global levels, and therefore needs a framework that reflects this. The universally agreed legal instrument, i.e. the UN Convention on the law of Non-Navigational Uses of International Water Courses is useful in providing guidelines, principles and a certain degree of stability to the process of creating workable regional agreements. The UN and its Special Agencies, Regional Banks and other organizations also need to cooperate. It is anticipated that all these institutions should rely their information of land surface processes in the basin on information resulting from space programs.

Conclusions

International space programs are very expensive and a result of lots of hard work. The resulting satellite data are easily available through electronic data active archives on the internet. But these exciting innovations are hardly used for integrated water resources management in river basins, neither nationally nor internationally. There is something structurally wrong in disseminating the data and water resources managers are not aware of its existence. Remote sensing scientists are typically organized in their own disciplinary community, which is only little confronted with water conflicts. Remote sensing scientists are satisfied by solving remote sensing from a physical perspective. They are not encouraged to work with end-users, and are perhaps not interested to do so. It is suggested that water professionals make colleagues aware of the new possibilities. Organizations such as International Association of Hydrological Sciences could do that for developed countries and the International Commission on Irrigation and Drainage for developing countries.

The looming water crisis in international river basins can be partially alleviated by creating trust and faith through the use of objective data relevant to water resources management. International databases such as the ones nowadays emerging in relation to the EOS program can contribute to that. Political neutral organizations or consultants could process the raw data into factual land surface information. The emerging trends in space technology, geographical information systems and their applications, coupled with developments in numerical hydrological modeling should be oriented towards maximizing benefits of all stakeholders.

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