Water Quality Accounts for the Swakop Basin in Namibia

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Introduction

The current and planned activities in the Swakop Basin will have strong impacts on the availability and quality of water resources. In order to minimize negative impacts and to develop environmentally sound strategies for social and economic development it is of paramount importance to understand the distribution and quality of water resources, sources of undesirable substances and the processes affecting them. A Strategic Environmental Assessment (SEA) has been initiated that assesses all the sector development scenarios in the Swakop Basin, where further water quality assessment has to be integrated. One part of this SEA is a Water Quality Balance Study for the River Catchments which aims at providing information on the water quality balance, groundwater availability from the alluvial aquifers and surface water resources and their contents, and to make future recommendations for remediation and abstraction constraints so that ecosystems and future water usage are not negatively impacted. This Water Quality Balance Study for the Swakop River Basin aims at providing information to the SEA (and SEMP) on the water quality balance for surface- and groundwater availability, by looking at key representative substances of water quality, such as Nitrogen (N), Chloride (Cl), and Cadmium (Cd) or Uranium (U), their sources and distribution in order to make future recommendations for water abstraction constraints and remediation.

Background

Namibia is one of the most arid countries in the world with more than 80% of the country being desert or semi-desert (Lahnsteiner et al. 2007a). Only five rivers, situated along its northern and southern borders, are perennial. Within the country the numerous rivers are all ephemeral and only flow after intense rainfall. With its total length of about 460 km the Swakop River is one of the biggest ephemeral rivers of Namibia, rising at the Khomas Highland and draining westwards into the Atlantic Ocean, south of Swakopmund. The Swakop drains a catchment area of 30,100 km^2 extending from the mouth into the Atlantic Ocean at Swakopmund over Otjimbingwe and in the east to about 50 km from Okahandja, and in the south to Khomas Highlands outside Windhoek. The highest point of the watershed is located at 2480 m. Annual rainfall varies from 0 mm in the lower reaches up to 475 mm in the eastern Khomas Highlands. 39% of the catchment area experiences rainfall that exceeds 300 mm per year, and up to 80% of the catchment experiences annual rainfall above 100 mm. The Swakop Basin has the most developed infrastructure in Namibia (CSIR 1997). Along many mines and farms it also comprises numerous towns including the capital of Namibia, Windhoek.

The Swakop Basin, which includes the major Khan River tributary is at 30 100km^2, the largest of the Westward- flowing Rivers grouping. It is also the most developed of the basins, both in terms of water resource developments and urban settlements. The Swakop River rises in the mountains to the east of Okahandja, and north-east of Windhoek, where mean annual precipitation is over 400mm. The unit runoff in this area is estimated as 7mm, which is lower than might be expected for this type of terrain, and the value may have been affected by the large number of farm dams in the catchment. The capital city of Windhoek falls within the Swakop catchment, other towns include Okahandja, Karibib, Usakos and Otjumbingwe and of course Swakopmund itself. There are probably close to 300 000 people living within the Swakop catchment. There are two major water supply dams on the mainstream of the Swakop River. The combined capacity of the two dams is nearly 120Mm3, which is more than three times the mean annual runoff of the river. There is also the Goreangab dam close to Windhoek, which is highly polluted, and the Avis Dam which reduce the amount of runoff available at Swakoppoort. Mean annual runoff in the Swakop River is 20.515Mm3/a at the Von Bach Dam. At the Swakoppoort Dam, further downstream it is estimated at over 37Mm3/a, runoff coming from the intervening catchment and occasional spills from the Von Bach Dam. By the time the river gets to the coast the mean annual runoff is estimated to be 26Mm3/a. the effect of the two dams has been to reduce frequency of flow at the coast from 1 in 1.9 years to 1 in 4.5 years. This higher than expected mean annual runoff at the mouth of the river is partly due to contributions from the Khan River, which is the most important tributary of the Swakop river. Mean annual runoff in the Khan River is estimated at 8.3Mm3/a at Usakos, reducing to just over 3Mm3/a at the confluence. The water resources of the Swakop River have been heavily developed both by bulk water suppliers and by farmers who have built large numbers of dams in the tributaries. (Study by Andre Mostert). The reduction of flow in the river has affected the quality of the water in the downstream reaches. There have been investigations into a recharge enhancement dam in the Khan River near Rössing, which would further reduce the availability of good quality water further downstream. A recharge dam further downstream could, however be operated in such away as to increase the availability and quality of water in the downstream reaches. The cost implications would however be major. The Khan and Swakop Rivers are gauged at several points allowing for reasonable estimnates of their runoff characteristics to be made. Accurate gauging stations in the desert are lacking. On the Swakop River the most downstream station is at Dorstrivier XX km from the coast, and on the Khan River at Usakos. A station in Sweakopmund can be re-opened during times of flood.

Standard Statistics

- Catchment Area: 30 100 km²
- Elevation Range: 0-2479 m
- Catchment Vegetation Types: Central Namib (9%); Semi-desert/Savanah transition (34%); Savanah (28%); Highland Savannah (29%)
- Stream Length: 460 km
- Mean Annual Catchment Precipitation: 275 mm
- Precipitation Range: 0-420 mm
- Mean Annual Runoff (maximum): 39 Mm3/a
- Median Annual Runoff (maximum): 15.2 Mm3/a (14)
- Number of rain gauges: 38
- Number of Runoff gauging Stations: 10

Project

The Ministry of Agriculture Water and Forestry (MAWF) is leading the implementation of Water Quality Accounting in Namibia. The works programme comprised the development of a conceptual model based on field investigations (surface- and groundwater sampling campaign) and exisiting database information, the implementation of numerical surface- and groundwater flow models of selected Swakop- and Khan river compartments (BIWAC, 2010) and subsequently an Intergated Geohydrological Model of the Swakop/Khan river catchment as basis for an improved monitoring, remediation, decision support system and licensing procedure through the regulator. The Integrated GeoHydrological Model of the Swakop basin (IGHMS) integrates hydrological data, calculates key hydrological processes and state variables and thereby defines hydrological boundary conditions of recharge, lateral inflow and outflow for compartments in a hydrologically consistent manner, in respect to key substances representative of water quality, such as Nitrogen (N), Chloride (Cl), and Cadmium (Cd) or Uranium (U), their sources and distribution in order to make future recommendations about water abstraction constraints and remediation. Numerical groundwater models can be plugged into IGHMS for a detailed and numerical modeling of specific compartments (BIWAC 2010). Results of the IGHMS are used to evaluate impact of water abstraction scenarios on stakeholders, mines and farmers.

Terms of References

The information required for the Water Quality Accounts and IGHMS study has been outlined in the terms of references.

Desk study

The following basic data need to be collected and summarized:

- Location
- Demographic overview and water demand
- Water utilisation and management
- Water quality, representative substances of water quality, such as Nitrogen (N), Chloride (Cl), and Cadmium (Cd) or Uranium (U), their sources, sinks and distribution
- Environmental issues
- Social issues
- Institutional and planning issues
- Review of objectives in Vision 2030, Millennium Development Goals, NDPs, NBSAP 2 and local development agendas that should be considered in the basin management strategies to be developed.

From sources and archive such as GROWAS, OMBMC, IWRM website, Municipalities responsible for Swakop Basin NamWater, Namibia Statistics Agency, DWAF and so forth relevant data and information will be collected and converted to formats suitable for the project. A project database will be created and data manipulation will include the formulation of thematic maps that will depict geographic perspective of the basin, catchment characters such as rivers, population density, towns, boreholes, water quality, surface water and groundwater flow etc., within an Arc-GIS environment. The generated maps will form part of the visual aids in compiling the status report.

The desk study will include an impact assessment investigating the impact of current land use on water quality which includes agriculture, bush encroachment and prosopis on basin hydrology and water quality. The assessment will offer recommendations for optimisation of water use in the different land use sectors, and remediation procedures.

Data Review

- Review of existing data sources (including links to websites) and identification of gaps

- Definition of water resources, integrated runoff-recharge hydrological and geohydrological model of the entire catchment
- Impact assessment of land use (including agriculture, bush encroachment and Prosopis) on the hydrology and water quality of the basin and proposals for economic optimisation of water use by this sector
- Status of stakeholder participation, awareness-raising and water education

The review will inform the current status of the basin's demography, water demand, utilization and management as well as quality will be carried out. The review will also investigate the environmental and social issues in the basin as well as issues that are related to institutional matter and planning. Further a review of Vision 2030, Millennium Development Goals, NDPs, NBSAP 2 and local development strategies will be considered as in-put into basin management strategies. An analysis of stakeholder participation, awareness raising and water education will also be done.

Management Plans

- Water demand and conservation, management of abstraction licences (permits)
- Water quality management and pollution prevention, including vulnerability assessment of water resources to pollution
- Monitoring and reporting: Collection, interpretation and sharing of data, database and GIS development
- Readiness and response plans in case of flood events or water supply disruptions
- Capacity-building of the Swakop Basin Management Committee
- Institutional development and capacity-building

A comprehensive implementation framework of the basin plan has to be compiled, outlining the role players (key stakeholders) and timeframe of the actions completion.

Data requirements

- <todo> Runoff daily for the last 25 years (since 1990) for all stations within the basin</todo>
- <todo> Rainfall, Temperature and relative humidity daily for the same period for at least three, better 5 stations</todo> covering the west east transsect
- <todo> Groundwater levels in the alluvial aquifer from boreholes daily</todo>
- <todo> Production data for alluvial boreholes</todo>
- <todo> Dams Data, volume-stage relationship, stage time series, area and abstraction</todo>
- <todo> Geological map</todo>
- <todo> Borehole map</todo>
- <todo> Station map for Runoff and met stations</todo>
- <todo> Accounts of representative substances of water quality, such as Nitrogen (N), Chloride (Cl), and Cadmium (Cd) or Uranium (U), their sources, sinks and distribution</todo>

State of the art and literature review

A detailed Study of the management of the upper Swakop Basin is given by http://www.iwrm-namibia.info.na/downloads/namwater-workshop-reports-upper-swakop-basin.pdf. A comprehensive study and development of Integrated Geohydrological Model (IGHMS) is given by sea_erongo_paper_ab_ck_final.pdf. A water quality study of the swakoppoort Dam has been conducted by lehmann_f_2010_ma.pdf. The Impacts of upstream uses on the alluvial aquifer of the Swakop River, Namibia, has been given by marx_v_2009_da.pdf.

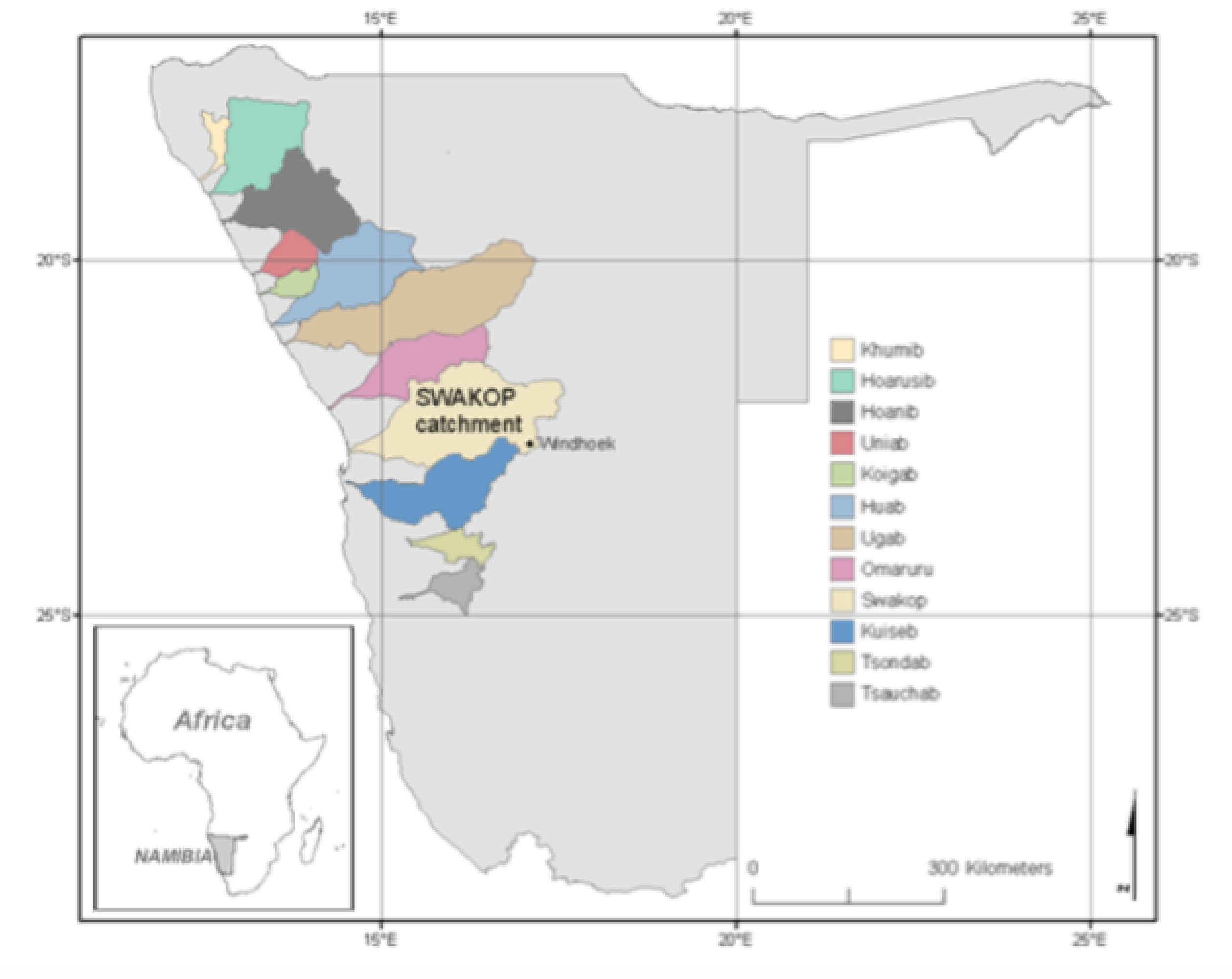

Figure 1. *The location of Namibia in Africa and the westwards draining ephemeral rivers in Namibia |Marx 2009 based on (P. J. Jacobson et al. 1995)*

According to Strohbach (2008) the Swakop Basin has a basin area of 21 010.149 km². Struckmeier & Rambow (2002) have described the hydrogeology of Vogelsberg within the Basin. The use of scarce water resources is described by Schneeweiss & Müller (2009). The water management at Roessing Uranium was has already been described by Smit & Brent (1991).

……….Geyh & Ploethner (1995) have investigated the isotope composition of groundwater in the Omaruru Basin. A good insight to undergroundwater storage and aquifier response to artifical recharge in the Omararu delta is given by Aquifer response to artifical discharge, Omaruru Delta Namibia and see e.g. Seely et al.

Hydrogeology

The characteristics of recharge dams in ephemeral rivers is described at see e.g. Seely et al.. A summary of hydrological conditions and data is given by Namwater 2014.The geography and associated characteristics of Swakop catchment area is given by Jacobson et al.(1995), page 138.

Meteorology

Meteorological data are available for stations at Walvis Bay and Windhoek. Daily rainfall is available at Walvis Bay and at Windhoek. Windhoek is the elevated station with higher rainfall and semi-arid conditions. Walvis Bay is located at the coast in an arid climate with low rainfall amounts.

Maximum and minimum temperature are also given at Walvis Bay (Tmax, Tmin) and at Windhoek (Tmax, Tmin) on a daily basis and are used to evaluate potential and actual evaporation from open water surfaces and vegetated land. Relative Humidity is given at both stations at 8:00, 14:00 and 20:00 (see Walvis Bay 8 a.m., 2 p.m. and 8 p.m. and Windhoek 8 a.m., 2 p.m. and 8 p.m.).

Meteorological data can be used to calculate evaporation. Evaporation rates for Namibia are given in the Namibian Evaporation Map. Although these values represent potential evaporation, they seem to be rather high and exagerated. Therefore, an independent re-evaluation of evaporation is carried out based on station data.

Hydrology

Runoff in the Swakop Basin is monitored at ….station (Station number: 2971M02). The station is located at Lat: -22.43333333 and Long: 16.66666667 at an elevation of 1072 m. Daily data of runoff since 2006 indicate a strong inter-annual variability of runoff. The file is also available as comma separated value file.

Station	Name	Latitude	Longitude	Elevation
#	#	degrees	degrees	m a.s.l
2971M02	…..	-22.43333333	16.66666667	1072

- Graph: runoff as a function of time.
- Annual sums from 1.10. until 30.09.
- calculate mean specific runoff: annual runoff in liters (or mm) divided by basin area in m²
- calculate runoff coefficient: mean annual specific runoff in mm/m² as percent of annual rainfall in mm/m² - the expected value is 4 %.

The runoff coefficient of surfaces in the Swakop basin varies strongly. As shown by the unit runoff map of Namibia the Swakop basin hosts some of areas with the highest runoff coefficients in Namibia. Granite is producing up to 30 % of runoff per unit area. However, in the lower part of the Swakop basin, areas with low runoff coefficients of only 1-5 % prevail. Therefore, most of the runoff is produced in the upper part of the basin, not only because of higher rainfall but also because of higher runoff coefficients. In the lower part of the basin runoff production is small. In addition runoff is reduced by transmission losses in alluvial channels.

Methodology

Integrated Geohydrological Model (IGHMS)

IGHMS was developed with the software package SIMILE of Simulistics ©. This software has been proposed for explicit environmental modeling, especially for integrating processes of different disciplines. The software allows visualizing the complete program structure. Non- programmers can follow the flow of water and resources and relate to different modules and compartments or processes of the model. This was an important aspect as the model will be used by local stakeholders and decision makers for remediation procedures and in situations of potential conflict. The model consists of a sequence of compartments. For each compartment all inflows and outflows -substances exchange balance accounts- are calculated based on hydrological processes. Each sub-model (Swakop/Khan) represents all relevant geo-hydrological processes: channel flow, evapotranspiration, transmission losses and groundwater recharge, pumping, lateral groundwater inflow and outflow, and groundwater exchange with the basement aquifer, in relation to the exchange of key substances, their sources and sinks, such as Nitrogen (N), Chloride (Cl), Cadmium (Cd) or Uranium (U).

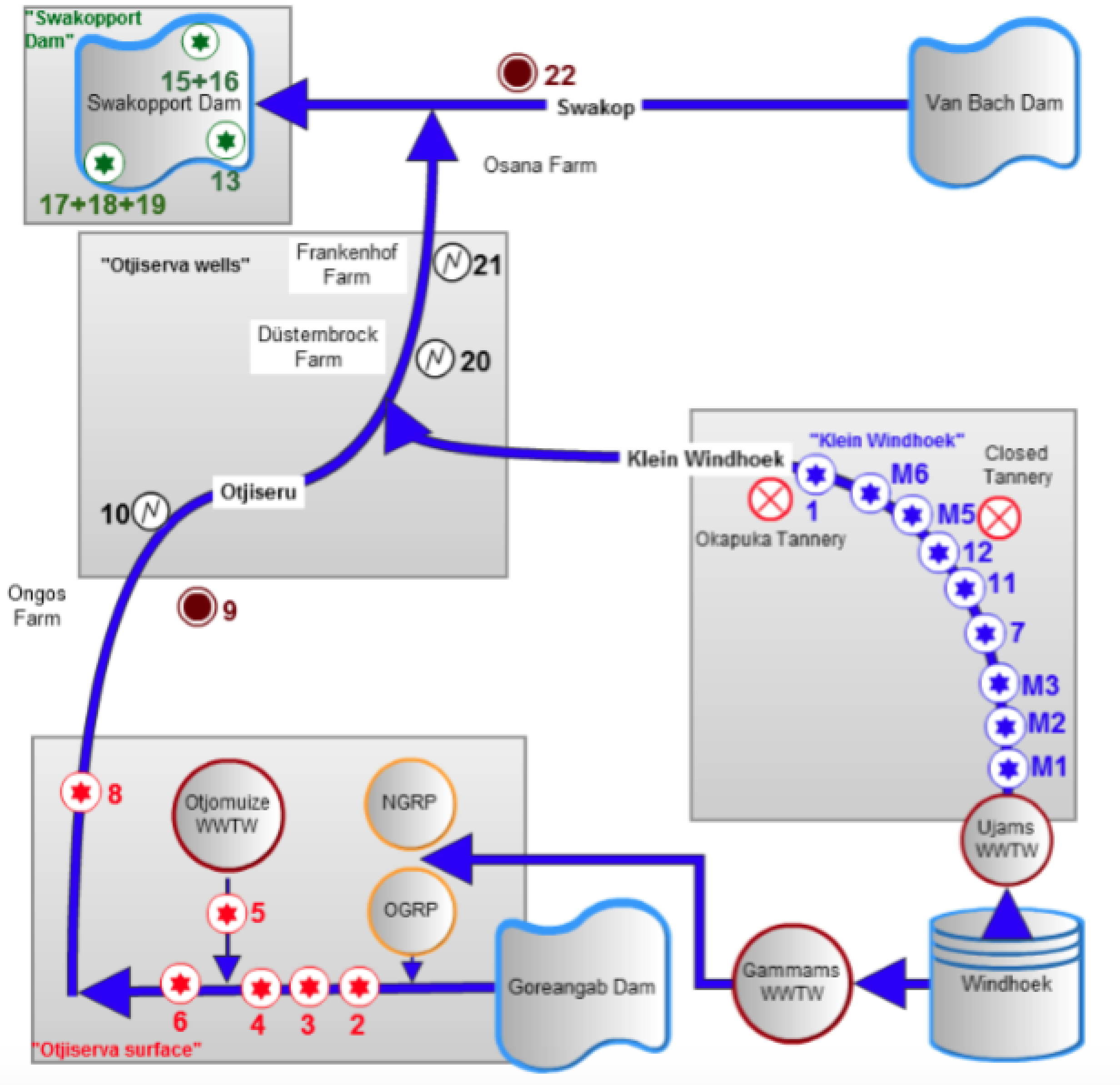

Figure 2. *Flowchart of the different water treatment and reclamation plants in Windhoek. The arrow color is symbolizing the water type. Red: wastewater, blue: dam, stream or treated water and green: reclaimed water.*

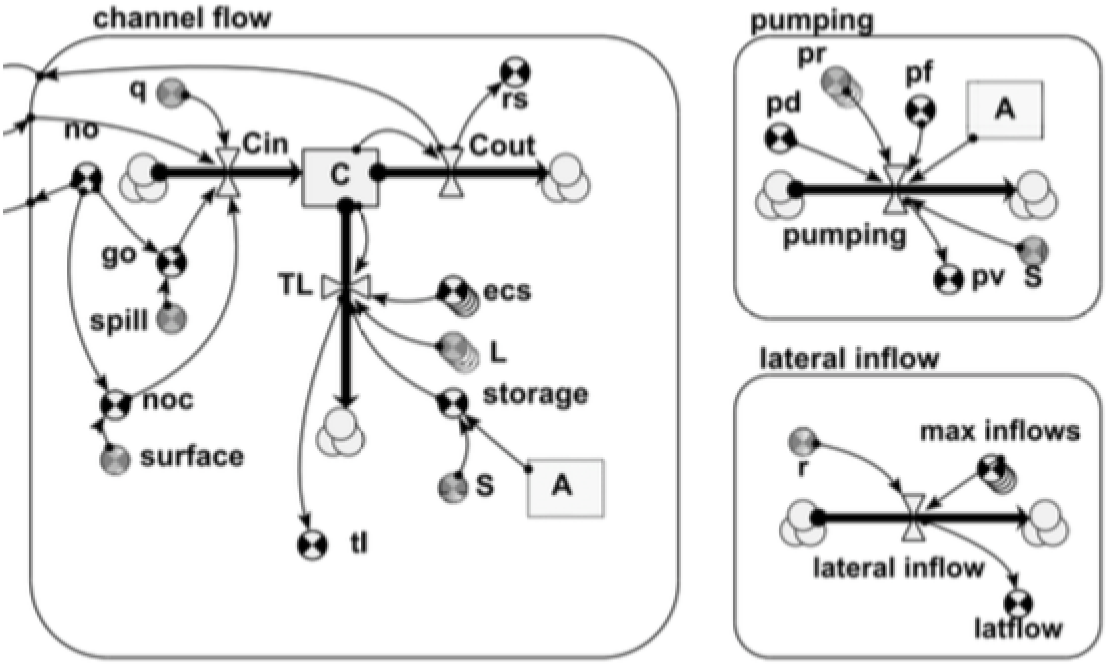

Figure 3. *Part of the model structure showing surface runoff, transmission losses, pumping and recharge: q=runoff, Cin=channel inflow, Cout=channel outflow, rs=surface runoff. TL=transmission losses depend on L=length of the compartment (km), ecs=extinction coefficient (m3/s per km) and are limited by storage (S) of the alluvial aquifer (A). The model also takes into account spill flow from an upstream reservoir (spill), while no, go and noc are indices for the compartment number. Pumping is controlled by pumping rate (pr), borehole depth (pd) and a flexibility (pf) of pumping at low storage volume (S) of the alluvial aquifer (A) resulting in a lower pumping rate (pv). Lateral groundwater inflow to the compartment depends on max. inflows calculated from Boussinesqs law and basin recharge ®.*

The Swakop Geohydrological Model will represent the basin and sub-basin structure, rivers and aquifers as compartments and will include water content schemes, sources and abstraction points. The model has a compartment structure. Flows between compartments are described based on physical principles. Water levels, water storage, evaporation, runoff and recharge and also water quality can be specified for each of these compartments. Each compartment is associated with a sub-basin with specific surface properties, land-use characteristics and storage properties.

The model is driven by hydro-meteorological data (rainfall and evaporation parameters temperature, relative humidity and solar energy balance. These data can be loaded to the model (if readily available). In case, data are not available or available with delays in data processing average monthly seasonal regimes of rainfall and evaporation are available that can be used as proxy input data. In addition, hydrological station data, boreholes with their respective abstraction rates water storage and distribution infrastructure are included.

The model runs on a monthly or daily basis (as chosen by the user) and converts rainfall to runoff and soil water storage and soil water storage to evaporation and groundwater recharge based on approaches that have been developed in Namibia or proven right in this regional context (Namibia antecedent runoff model as in Hughes & Metzeler (1998) evaporation model for alluvial aquifers (Hellwig (1973), and recharge estimation methods for direct and indirect alluvial recharge (Klock, Kuells, & Udluft, 2001, Dahan et al., 2008, Kuells, 2000). Runoff is routed through the Swakop and recharge to local aquifers and to the alluvial aquifer compartments is calculated. The user can retrieve runoff hydrographs and tables of available resources at each of the compartments and groundwater level and current storage for each of the local aquifers.

The geohydrological model facilitates integrated water resources management as it integrated all impacts and converts these to water levels and storage volumes compared to potential storage and juxtaposed to critical management lines (red lines). Critical water levels can be defined and projections run how water levels will drop in the future given the known and current uses. Options for demand management are included: The response of the aquifer systems to management options can be simulated and evaluated.

The geohydrological model can also be used as decision support system. Boreholes are included and scenarios for different abstraction rates can be run (see Bittner, Marx & Külls, 2011: SEA for the Central Namib Uranium Rush: - Geohydrological Model of the Swakop River, Phase II.). The model will show the impact on all other connected groundwater compartments. The model can therefore be used for impact assessment and to simulate requested abstraction rates, before water rights are issued.

Finally, the geohydrological model will include features to provide summary tables for sub-basins and compartments for management purposes. Theses summary tables are compatible with recommendations for IWRM standards and with the UN water accounting approach. The hydrology and management of Dams within the Swakop Basin can be included as an option.

Results

References

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