Evaluation of Water Resources State Parameters with Using SWAT Model

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Abstract

Water scarcity and deterioration of water quality affects water resources availability which becomes severer under the climate change and urbanization process. Study of the water resources formation is important due to the shortage of water and urban development on the territory of catchment areas.
SWAT model has been used to evaluate water quality, determine factors, which influence river flow parameters. The boundary level of urbanization, deforestation and crop areas in land use for ecological state deterioration of watershed was determined.

Key words: agro-hydrologic model, ecological state, flow, Simferopol reservoir, SWAT, water quality.

1. Introduction

By the amount of local water resources the Autonomous Republic of Crimea (AR Crimea) refers to the regions under water stress. The problem of the availability of water resources (Crimean water availability is 4.25 times as small as the average one for Ukraine), water quality and access to the water resources are very important for the peninsula. Local water resources, which are formed in the mountain and foothill parts of the peninsula, mostly, have a normal quality and they are primarily used for drinking water supply and partly for irrigation. But the main source for the Crimea is the Northern Crimean Canal which provides about 80% of water.

Local water resources play a significant role in the portable water consumption of a number of settlements and used for irrigation, especially in the foothills of the peninsula. The local runoff formed by rainfall and snow melting is characterized by high variability both within a year and annually.

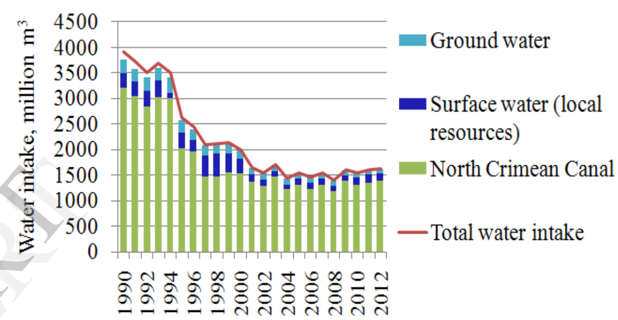

Figure 1. Water intake in AR Crimea (data of Crimean Basin Department of Water Resources [1, 2])

The change from the planned economic system (Soviet Union) to the market model has led to the significant changes in the structure of water consumption. Lack of investments still creates the problems for treatment facilities reconstruction and modernization, leading to the increase of a number of pollutants discharged into the water bodies. Besides, urban development of watersheds without prior assessment of anthropogenic impact on ecosystems increases water resources deterioration.

State environmental monitoring system is considered to be the main source of water quality information in Ukraine. In most cases, it can be concluded that there is insufficiency of observation points (e.g. 9 points in Simferopol reservoir catchment area) and sampling frequency (mainly quarterly, and only water intake samples are taken daily) for the evaluation of water resources state parameters. SWAT model [3] gives the possibility to estimate water quality using simulated parameters to fill gaps in monitoring data, to obtain obvious characteristics of ecological status of ecosystem, especially in the situation with the lack of funds for sampling.

2. Study Area and Data Used

The Salgir River originates from the confluence of Angara and Kizil-Koba rivers in the North side of the Main range of the Crimean Mountains and flows northeastward 204 kilometers to the Sivash Gulf [4].

Simferopol reservoir was built on the Salgir River 57 year ago for drinking water supply, irrigation and electricity purposes. The catchment area of the reservoir is 302 km^2; it lies between 34°19’N and 34°8’N latitude and 44°48’E and 44°53’E longitude, as shown in figure 2.

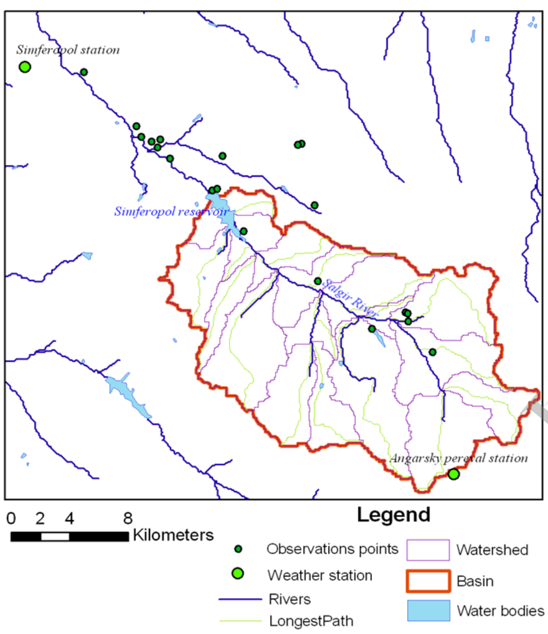

Figure 2. Simferopol reservoir watershed

The contour lines map of Simferopol reservoir basin was built using Spatial Analyst extension in ArcView 9.3 (figure 3).

The elevation of the Simferopol reservoir basin is between 274 and 1447 meters. The annual rainfall of the territory varies from 518 to 919 mm depending on the altitude. The long-time average annual flow of the Salgir River (Simferopol reservoir dam location) is 34.12 million m^3, with the river discharge about 1.08 m^3 per second (the coefficient of variation = 0.56, skew coefficient = 1.41).

The agricultural lands occupy 39%, forests – 46.7 % of the total land use in the watershed. The average crop yield for grain crops is 2-2.5, the annual grass crops – 10-12, the perennial grass crops 12, and the corn for silage – 12-13 tons per hectare.

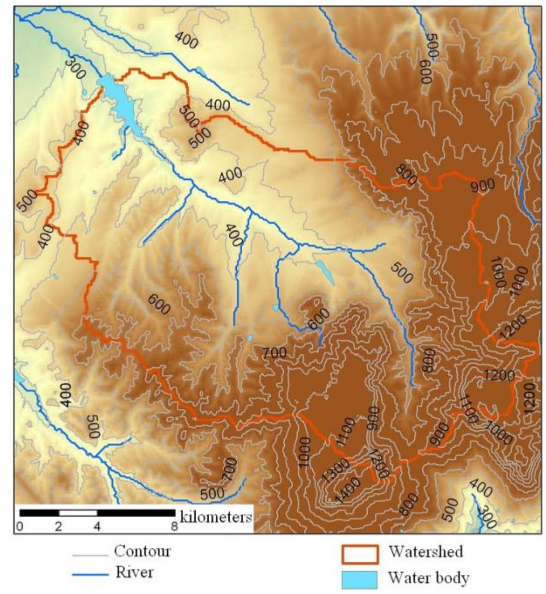

Figure 3. Contours of Simferopol reservoir watershed

To start modeling the state of water resources the following input data are used [5]:

a) digital elevation model (DEM), resolution 90 m;

b) land use and soil maps;

c) weather data, including maximum and minimum air temperature (C°), precipitation (mm/day), wind speed (m/sec), solar radiation (MJ/m^2), relative humidity (fractional) and potential evapotranspiration (mm/day) for 1978-2012 period;

d) reservoir inflow (m^3/day), reservoir water quality data (monthly);

e) point source (m^3/month), water quality data (monthly).

3. Methodology

The Soil and Water Assessment Tool (SWAT) is ‘a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over the long periods of time’ [3].

The SWAT model can be run under the different GIS platforms.

ArcSWAT was developed at Texas A&M and uses ArcGIS platform. ArcSWAT is ArcGIS based extension with a graphical user interface for the SWAT model. ArcSWAT interface is public domain software.

Support is provided through the SWAT user website and several user groups and discussion forums. Usage of ArcGIS implies license availability (at least for a system and one more extension necessary for the model work – Spatial Analyst). Download link: http://swatmodel.tamu.edu/ documentation.

MWSWAT is a similar tool, but it uses an open source GIS platform – MapWindow GIS. This product was developed at Geospatial Software Laboratory, Idaho State University, USA. Download link: http://www.waterbase.org/.

BASINS 4 (Better Assessment Science Integrating point and Nonpoint Sources, the U.S. - Environmental Protection Agency, USA) is 'a multipurpose environmental analysis system designed for use by regional, state, and local agencies to perform watershed and water quality-based studies'. It includes OpenSWAT as one of the built-in models (also HSPF, PLOAD, SWMM, AQUATOX, WASP). Download link: http://www.epa.gov/waterscience/BASINS.

Advantages of SWAT: ability to simulate watersheds without water quality observation data; possibility to evaluate an impact of alternative management practice, for example, on water quality; option of long-term period analysis and forecast [6].

Limitations of SWAT: daily time step; simplified soil moisture dynamic model; no option of single event flooding; no option of simultaneous modeling territory fed by river and irrigation canals [3].

4. SWAT model results analysis

SWAT simulation procedure includes, in general, three main stages [7]:

- preparatory stage (gathering of the land use, soil and weather data, and creation of the databases);
- setup and run the SWAT project (includes watershed delineation, creation of hydrologic response units);
- editing SWAT parameters and re-run (also, after calibration and verification).

DEM was downloaded as output from The Shuttle Radar Topography Mission (SRTM) – 'SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA)'[8].

General information about land use was downloaded from WaterBase project web-site (http://www.waterbase.org/download_data.html) and complemented by local maps data. The processed land cover on the Simferopol reservoir catchment area is shown on figure 4.

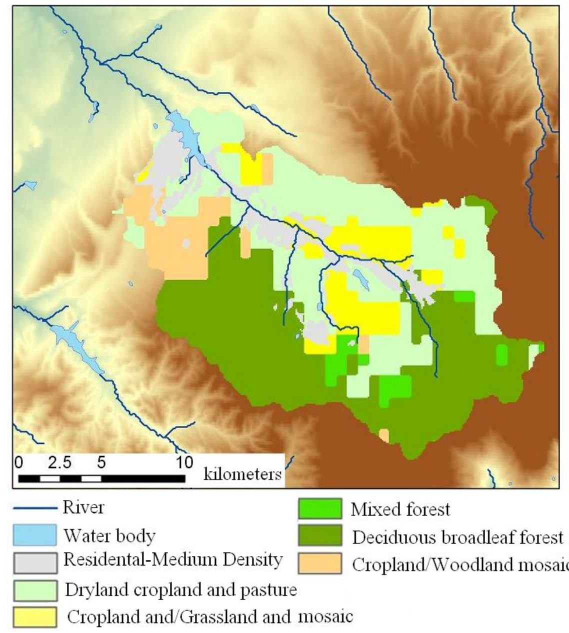

Figure 4. Land use map of Simferopol reservoir basin

A MWSWAT run result of flow simulation in comparison with statistic data (precipitation and flow) is placed in figure 5.

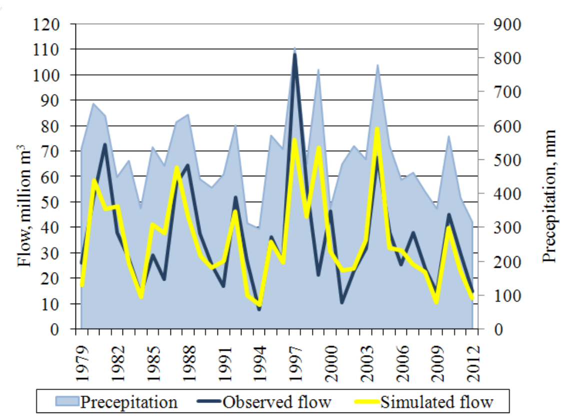

Figure 5. Run result of flow dynamic

To calibrate and verify the results of the SWAT model the following data are used (simulation using MapWindow GIS):

- statistic meteorological data (Database of Central Geophysical Observatory, Kiev, Ukraine and DB of Hydrometeorology Centre of the Autonomous Republic of Crimea, Simferopol, Ukraine), inflow data (DB of Salgir Water Management Department, Simferopol, Ukraine), available only on request;

- open source land use and soil data (WaterBase project [9]);
- local land use and soil maps [10];
- water quality data (DB of Simferopol Drinking Water Supply and Sewerage Company, Simferopol, Ukraine), available only on request.

Calibration and verification of the model have been done in two steps. At the first step, the comparison of statistic and simulated flow in cubic meters (correlation coefficient) was carried out.

The second step includes the evaluation of simulated reservoir water quality data with monitoring data.

There are two rain gages located in/near the watershed area of Simferopol reservoir – Simferopol station (latitude 45.05°N, longitude 33.97°E, altitude above sea level 181 m) and Angarsky pereval (latitude 44.75°N, longitude 34.33°E, altitude + 765 m).

The simultaneous usage of data of both stations gives the possibility to simulate flow dynamics and to estimate the influence of meteorological factors, though differences in absolute values and, most probably, indicates the necessity of (one more) another precipitation rain gauge installation into the Simferopol reservoir basin.

Figure 6 shows the comparison between the simulated flow and the measured data.

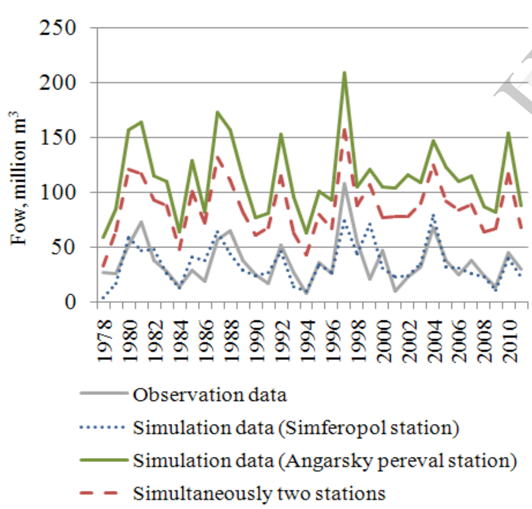

Figure 6. Statistic and simulated Simferopol reservoir inflow

Correlation coefficient of the flow (only under the data of Angarsky pereval station) is equal to 0.85. Statistic and simulated flow dynamics mainly coincides, but these data differ greatly for absolute values. Simferopol station is located outside the watershed territory; correlation coefficient of the flow is 0.73 (based only on this station data), flow dynamics is not so relevant, with opposite direction in 1999, but after excluding this year, data correlation has increased up to 0.86, and has shown much closer relation than when using the data of both stations simultaneously.

Verification with observation data (Database of Simferopol Drinking Water Supply and Sewerage Company) for NO_3, NO_2 and CDOD (2005-2011) has been done to evaluate the simulation results reliability of water quality.

Correlation coefficient of nitrate is 0.80, nitrite – 0.83, CBOD – 0.92 (figure 7), that indicates reliable water quality simulation of Simferopol reservoir by MWSWAT.

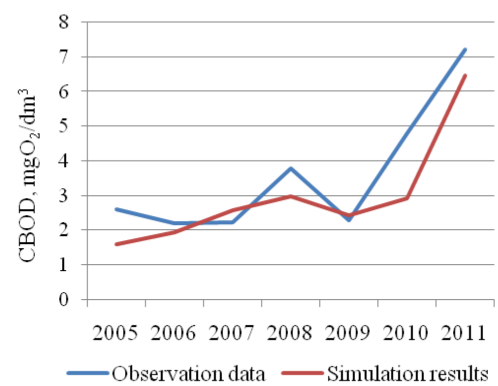

Figure 7. CBOD observation and simulation

To estimate the possibilities of evaluation of ecological state of water resources by means of SWAT model, statistic water quality data in Simferopol reservoir was collected and processed (e.g. statistic and simulation nitrate concentration, see figure 8, table 1).

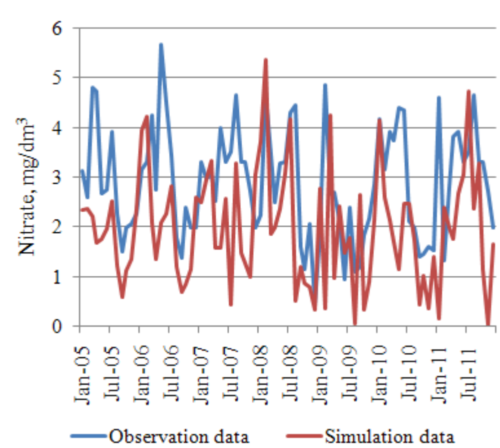

Figure 8. Statistic and simulation nitrate concentration in Simferopol reservoir

Table 1. Simulation and measured data

Data	Observation / Simulation data (annual)			
Year	NO2, mg/dm^3	NO3, mg/dm^3	Dissolved oxygen, mgO/dm^3	Turbidity, mg/dm^3
2005	0.13 / 0.05	2.9 / 1.8	10.9 / 11.5	2.2 / 0.7
2006	0.05 / 0.05	3.1 / 2.1	11.2 / 15.7	1.6 / 0.6
2007	0.02 / 0.05	3.6 / 2.1	11.0 / 11.5	2.4 / 0.8
2008	0.09 / 0.06	3.4 / 2.2	11.5 / 6.4	2.4 / 0.6
2009	0.06 / 0.09	2.5 / 1.7	11.7 / 33.8	2.0 / 0.4
2010	0.06 / 0.07	2.9 / 1.8	10.2 / 6.4	2.2 / 0.8
2011	0.02 / 0.04	3.3 / 2.1	10.9 / 13.0	2.4 / 0.5

5. Results and discussions

One of the factors, which substantially influences the water resources parameters (water quantity and quality), is a land use structure of the territory. The percentage increase or decrease of one of the land use type affects river flow volume and water quality.

The study has revealed that the critical percentage of land use for foot-hill Crimean watersheds state deterioration are (have to be at least) as follows:

- forest >50% of the total basin area;
- urban territories <11% of the total basin area;
- cropland <10% of the total basin area.

The research shows the relation of forest area (%) and annual inflow (million cubic meters) in the Simferopol reservoir basin expressed by equation:

$$y = 26.41 + 0.184x,$$

x – % forest land use on the watershed.

Forest reclamation has positive influence on the water resources accumulation, decrease of runoff peaks and inflow increase to the reservoir.

The relation between cropland area (%) and turbidity (mg/dm^3) in the Simferopol reservoir basin is expressed by equation:

$$y = 6.427+ 74.28x,$$

x – % cropland land use on the watershed.

One percent increase of cropland land use on the catchment area influences water quality, videlicet, the turbidity increases 39%. This value is very significant for the mountain watersheds.

Dependence between urban area (%) and CBOD (mgO_2/dm^3) in the Simferopol reservoir basin is expressed by equation:

$$y = - 0.340 + 0.187x ,$$

x – % urban land use on the watershed.

The percentage of urban area for the territory of the Simferopol reservoir basin is within the threshold level. But the continuing population growth and the expansion of the settlements territory may lead to the deterioration of water quality.

The study has revealed that the ecological state of the Simferopol reservoir basin is tolerable. However, the decrease of the amount of forest canopy at 10% and the continuing urban development along the valley of the Salgir River will influence both the inflow and water quality.

6. Conclusion

Agricultural lands and urban areas aren't to exceed critical levels. Otherwise it will lead to the loss of system flexibility, misbalance of integrated water management system and the worsening of the ecologic and economic state of the territory.

Spatial planning should be done with the preliminary analysis of impact of possible land use changes on water resources. That can be implemented by means of agro-hydrological modeling such as SWAT model, which allows simulating flow parameters depending on weather conditions and land use cover.

7. References

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