**Water and Nutrients Conservation in Syr Darya Watershed Extent in Kazakhstan**

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**Introduction**

Flood irrigation of cotton is practiced in the Syr Darya River Watershed of Kazakhstan. This practice is unsustainable due to seasonal unavailability in water supply and depletion of river discharges that were historically important at maintaining water levels downstream in nearby wetlands and the Aral Sea. Farmer surveys and expert opinions from government officials were used in Soil and Water Assessment Tool (SWAT) modeling to evaluate alternative irrigation practices and cropping systems that can conserve water in the Syr Darya River while maintaining farmer productively level in a similar manner.

**Objective**

The objective of this sub-project was to identify a suite of ecosystem services that are affected by the alternative agricultural practices modeled with SWAT.

Alternative practices to be evaluated included:

* Better irrigation water management (sprinkler and drip)
* Reduced fertilizer application
* Substitution of flood irrigated cotton with more water efficient crops (alfalfa, grapes, pomegranates)

Impacts of alternative practices evaluated included:

* Improvements in water conservation through reduced irrigation demand from agricultural lands
* Improvements in water quality (reduced phosphorus, nitrogen and sediment losses from farms)

**Methods**

As shown in the Figure 1, the watershed of Syr Darya was simulated for the period of 1981 to 2013 with the available reservoir release data from Chardara Dam for the period of 2009 to 2013. In Figure 1, it is also shown (in red color) Bugunski reservoir where most of the data were collected from surveys for this study. The modeled watershed was divided into 68 subbasins.

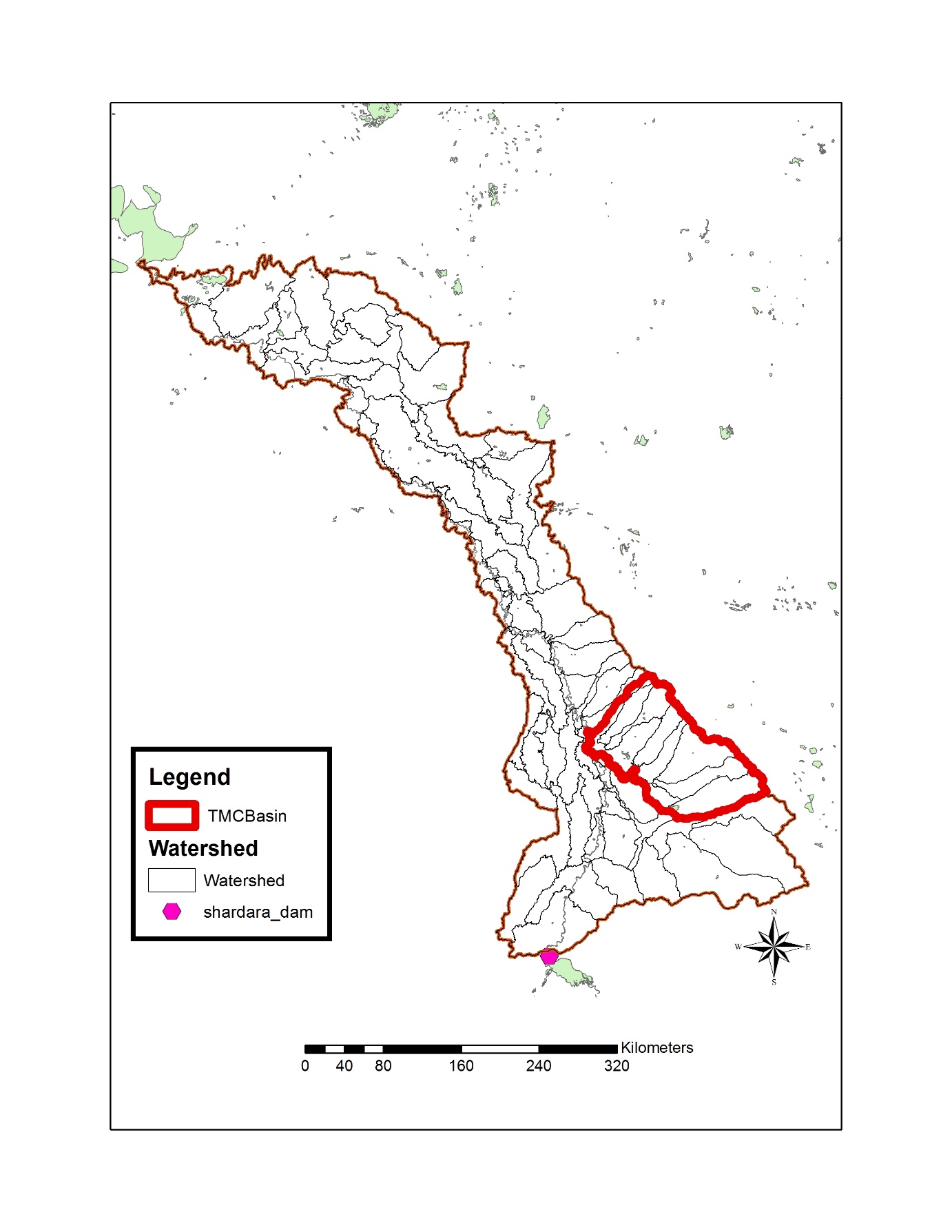
Farmer sample surveys were conducted in the Bugun, Steri Ikan and Karachik villages downstream of the Bugunski reservoir (a tributary river of the Syr Darya). Population of these villages is estimated at 4,100; 14,500; and 9,205 people, respectively. Surveys assessed cropping systems and irrigation practices used by farmers, along with costs of fertilizer inputs and prices paid to farmers for their crops. Survey results indicated that up to 60% of the farmers in these villages were willing to change from flood irrigated cotton to alternative irrigation methods and cropping systems. These alternatives could include drip irrigated cotton, drip irrigated orchard crops (e.g. pomegranates or grapes), and sprinkler irrigated alfalfa.

Figure 1. Syr Darya river watershed from Chardara Dam (red outline is the Bugunski reservoir watershed).

The SWAT model, is a biophysical model that is used to simulate the impacts of alternative land use management practices on crop yield, stream discharge, and water quality. It requires input data for daily weather, soil properties, elevation, land use and crop management. The data collected from the limited survey and expert opinions were used as input into the SWAT model to setup the entire Syr Darya river basin from the Kazakhstan country border based on the water release from the Chardara dam during 2009-2013 monthly data.

Initially using the baseline data, the SWAT model was setup to Bugunski reservoir such as cropping patterns, cropping management, water requirement, nutrient management etc. to make sure model was producing reasonable results. Only few gaging data for limited time were available to calibrate the flow. Then the calibrated model parameters were transferred to the large Syr Darya River Watershed to simulate the entire large basin flowing into Aral Sea. There were not enough data to calibrate spatially or temporally across the large basin.

**Results**

The total modeled watershed is 119,500 km2 from Chardara Dam to Aral Sea (Figure 1). Based on the baseline model setup of existing landuse and simulation of 1981-2013 period, the average annual hydrologic watershed budget is shown in Figure 2.

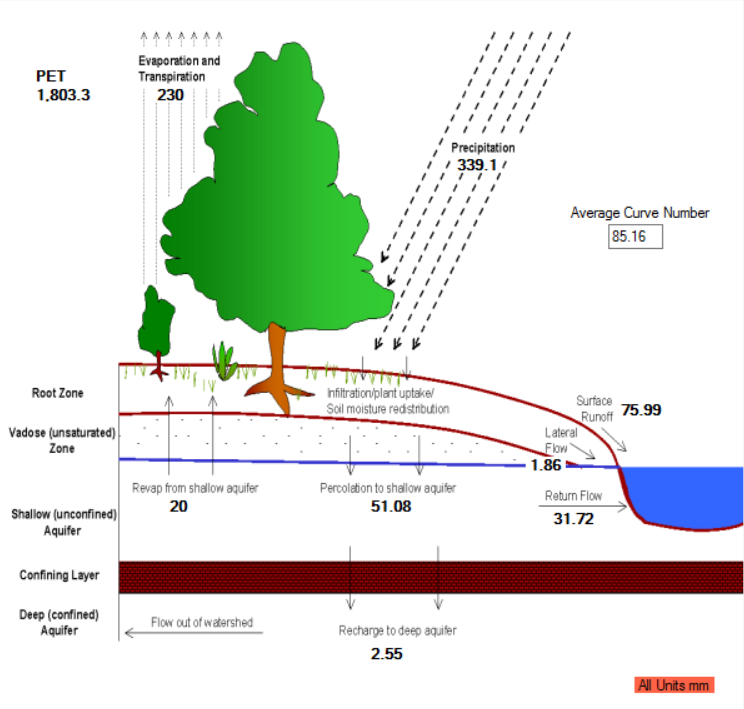


Figure 2: Hydrologic water budget of the Syr Darya basin 1981-2013.

With the average annual rainfall of 339.1 mm of which 230 mm is the evapotranspiration (ET) with about 109 mm of water yield from the 115,900 km2 watershed. This shows a long-term average of 68% of the hydrologic budget was the ET and 32% was the streamflow, 31% of streamflow was baseflow and 69% was direct runoff. The landuse distribution of the watershed is shown in Figure 3.

Figure 3: Landuse distribution of the Syr Darya River Watershed.

Table 1 shows average annual SWAT simulated output for hydrologic budget, sediment yield and nitrogen yields for the period of 1981-2013. Most of the irrigation were for the winter wheat in the southeast part of the watershed, rice along the major river with irrigation canals in the flood plains, cotton were mostly grown in Bugunski reservoir area and corn were above the floodplains also along the river. The agricultural land was only 9% of the total watershed area. Most of the sediments come from the steep slopes with barren or very sparsely-vegetated land with cool season grass. Cotton, corn and rice use most of the water for irrigation in this watershed. With cotton being the largest consumer of the water for irrigation with about 3% of the watershed in cultivated area. Also several of these landscapes have degraded due to excess grazing by sheep and goats.

| Landuse | Area Km2 | AWC mm | Irrigation mm | Rainfall mm | Runoff mm | GWQ mm | ET mm | Sediment t/ha | NO3- kg/ha | Org N kg/ha | Biomass t/ha | Yield t/ha |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| BARR | 55,064.22 | 148.97 | 0 | 291.9 | 97.84 | 6.94 | 176.17 | 11.67 | 0.1 | 4.59 | 0 | 0 |
| FESC | 33,011.49 | 101.86 | 0 | 504.26 | 88.88 | 105.04 | 264.77 | 35.89 | 0.14 | 10.13 | 2.33 | 1.66 |
| WPAS | 13,442.99 | 122.57 | 0 | 453.02 | 94.55 | 63.44 | 252.59 | 0.07 | 0.03 | 0.23 | 0.53 | 0 |
| RYER | 8,067.44 | 97.14 | 0 | 530.28 | 136.5 | 106.14 | 244.29 | 1.69 | 0.03 | 3.35 | 0.48 | 0 |
| WWHT | 3,501.80 | 62.42 | 275.16 | 539.39 | 163.52 | 104.21 | 485.86 | 2.81 | 1.67 | 8.51 | 16.92 | 5.23 |
| COTS | 3,057.46 | 130.92 | 559.22 | 422.96 | 96.01 | 105.07 | 734.87 | 7.99 | 0.51 | 10.69 | 4.82 | 0.4 |
| RICE | 2,014.20 | 176.95 | 361.78 | 210.91 | 5.61 | 0.25 | 562.52 | 0.02 | 0.12 | 0.09 | 4.03 | 1.54 |
| CORN | 1,018.67 | 171.59 | 483.99 | 771.25 | 173.55 | 182.64 | 861.57 | 1.55 | 2.22 | 10.14 | 33.12 | 11.02 |
| WATR | 291 | 122.74 | 0 | 247.64 | 0 | 0 | 1,211.48 | 0 | 0 | 0 | 0 | 0 |

Figure 4 shows the pathways to water quality movement in the landscape and in the soil as attached to direct runoff and sediment as well as subsurface movement. There were no field-observed data to calibrate, based on the experience and literature these ranges seems reasonable.

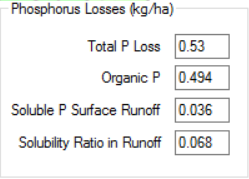
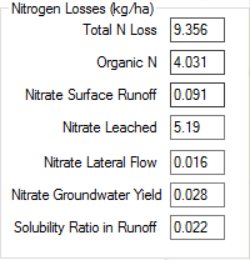
Figure 4. N and P pathways in the Syr Darya River Watershed (in kg/ha).

Figure 5 shows the average annual SWAT simulated sediment yield from the landscape simulated for the period of 2009-2013 since the reservoir release from Chardara data were available for only this period. As already noted, most of the sediment yield is from the southeast where the rainfall is relatively high with very steep slopes and very sparsely vegetated or barren land.

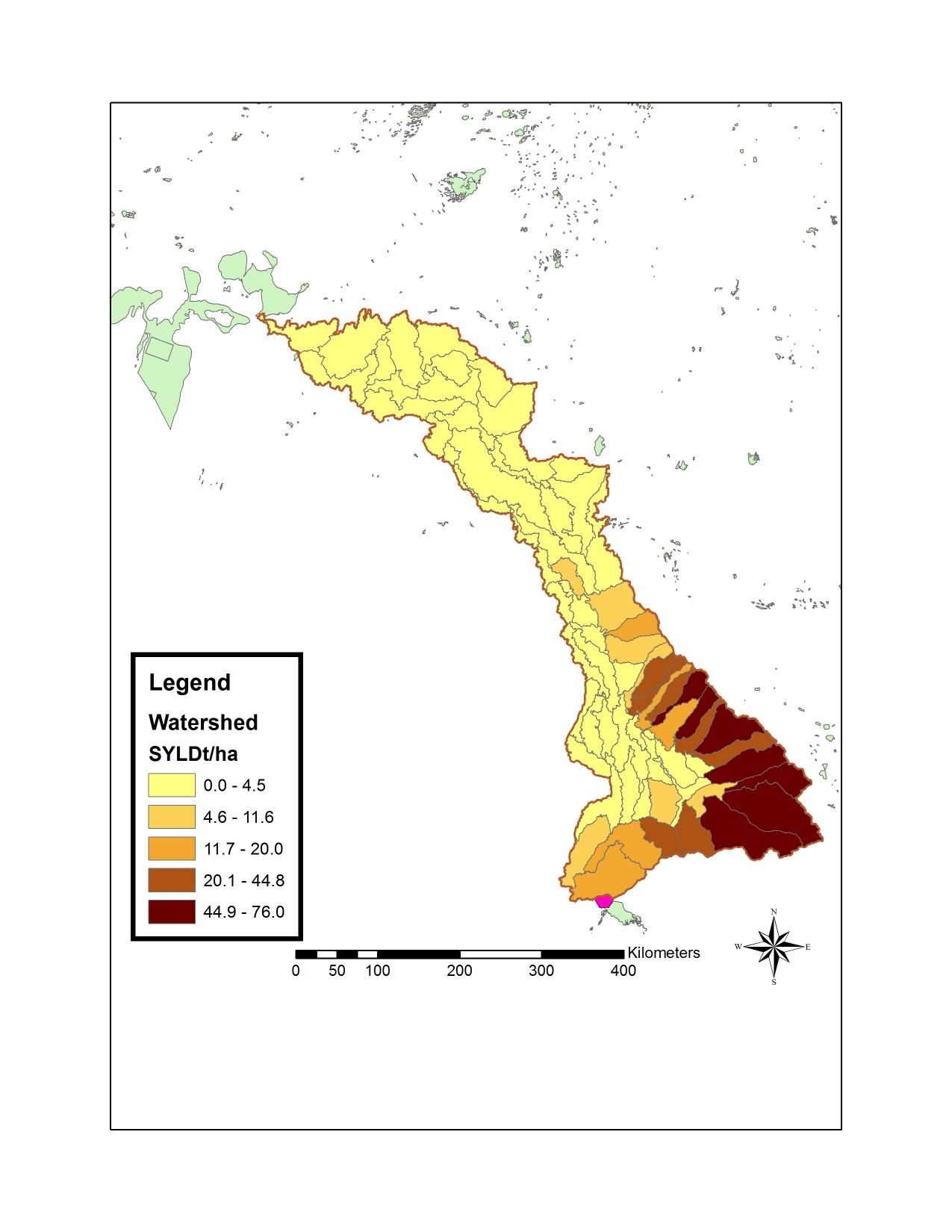


Figure 5. Average annual SWAT simulated Sediment Yield (in tons/ha) (2009-2013)

Figure 6 shows the average annual SWAT simulated total N and P contribution by the subbasin for 2009-2013 period. It is evident, due to high sediment the organic N and P contribution were higher in the south east part of the watershed. Relatively comparing with organic vs inorganic N and P, organic contribution were higher as shown in Figure 4 the pathways of N and P movement in the watershed.

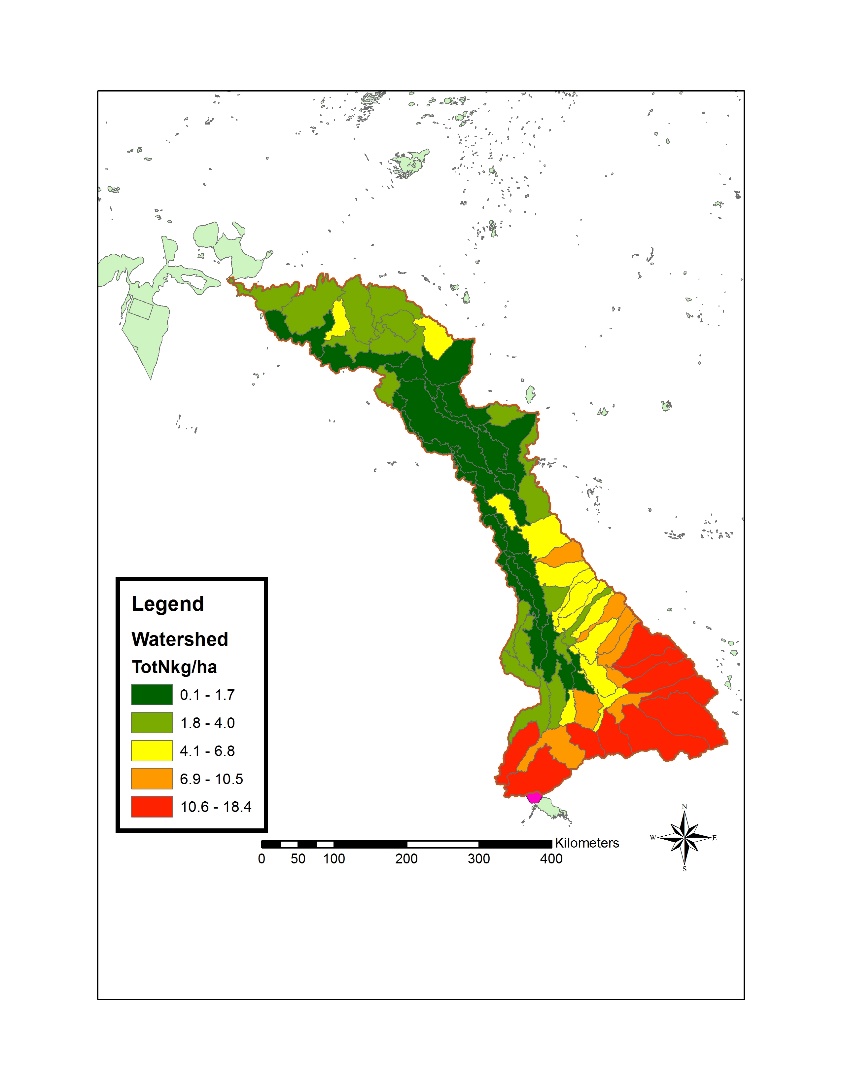
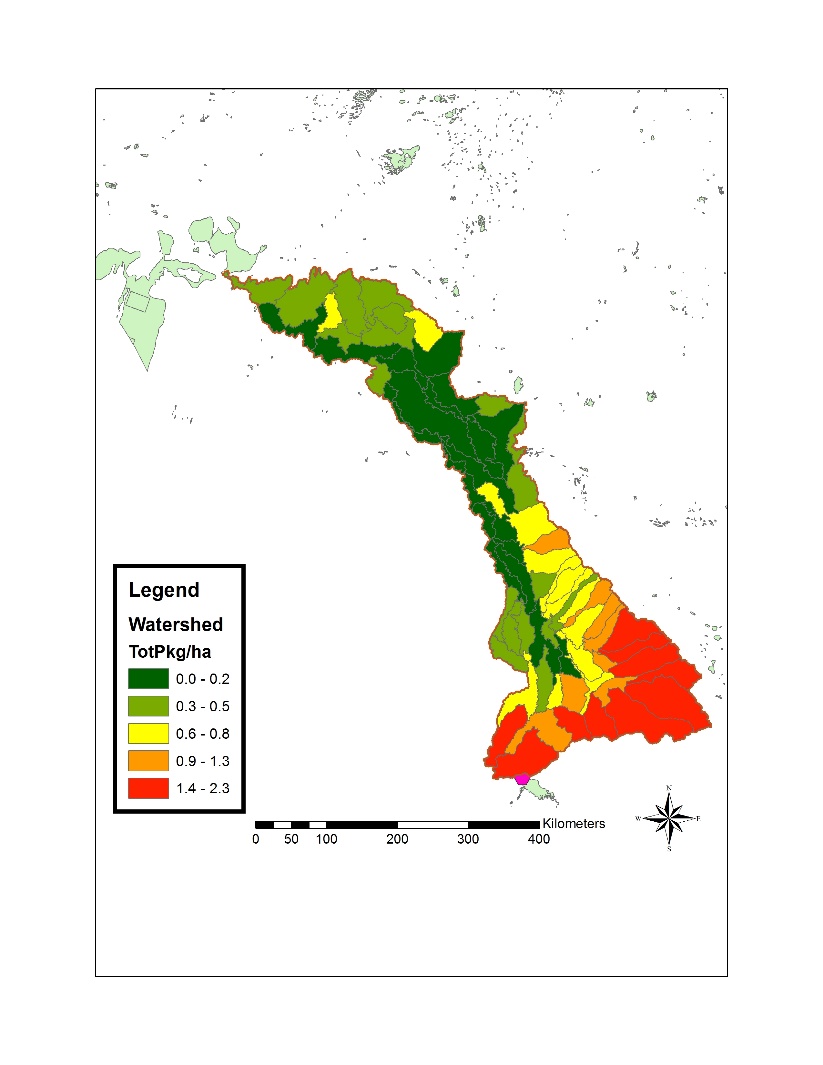
Figure 6. Average Annual SWAT Simulated Total N and P in Kg/ha for 2009-2013 by subbasins.

Figure 7 shows the average annual SWAT simulated soluble nitrates and phosphorus contribution across the landscape by subbasin for the period of 2009-2013 in kg/ha. Relatively, the contribution from the agricultural land was very limited at the subbasin scale as cropland was only 9% of the watershed and distributed throughout the basin. However, since most the croplands were located close to the water resources such as reservoirs and rivers, the local load from agricultural landscapes were higher. In addition, as the water moved from upstream to downstream, the water were abstracted along the river through diversions for irrigation and municipal use, the water quality concentrations were very high near the tail end of the watershed.

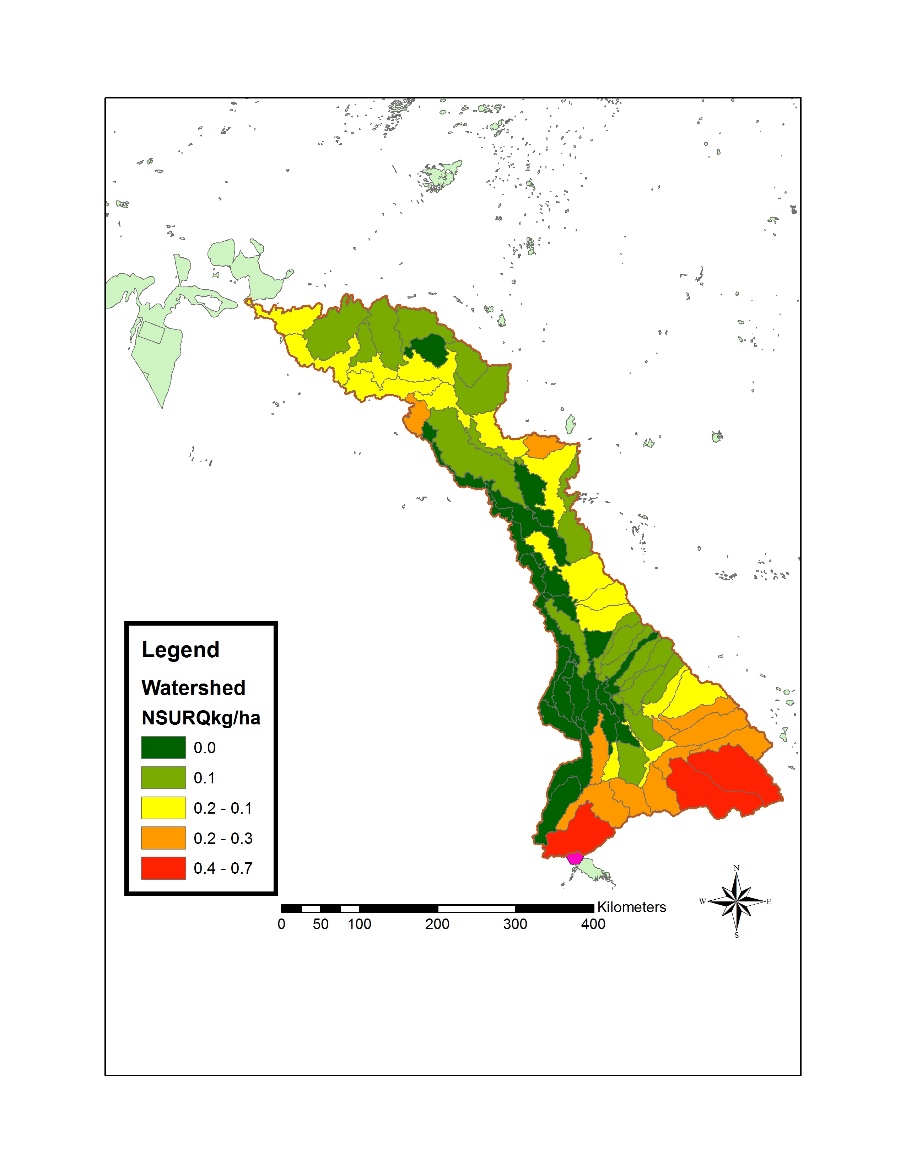
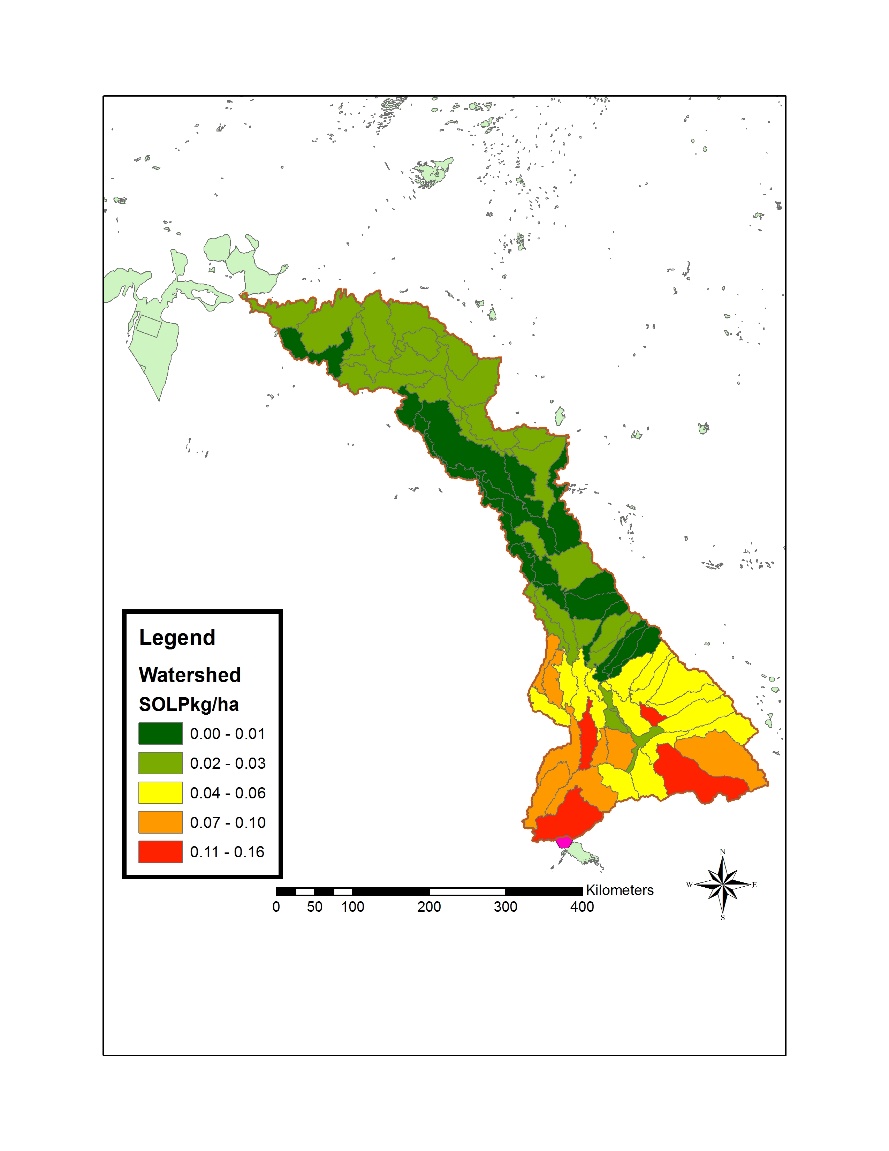
Figure 7. Average annual SWAT simulated nitrates and phosphorus in soluble form (2009-2013).

Figure 8 shows the total irrigation demand by year for various agricultural watershed in million m3. The average water demand was about 3.9 billion m3 (Bm3) per year for irrigation. This does not consider any of the irrigation efficiencies. If one assumes the irrigation efficiency of 50%, since most of these area are under flood irrigation, the annual irrigation requirement is 7.8 Bm3.

Figure 8. SWAT simulated irrigation demand in million m3 for all agricultural land (2009-2013)

Figure 9 shows the probability of exceedance curve for total N and total P in millions of kg at the watershed outlet that were reaching the Aral Sea Basin based on the SWAT model simulation for the period of 2009-2013. As the figure shows, the total N in the river is above 0.5 million kg or 500 tons of N and about 220 tons of total P reaching the Aral Sea by month.

Figure 9. Load duration curve of SWAT simulated total N and P at the watershed outlet (2009-2013)

SWAT scenario simulations

As it was done in the Bugunski Reservoir Watershed modeling exercise, both improved irrigation scenarios using sprinklers/drip system with higher irrigation efficiencies were simulated for the entire Syr Darya River Basin with reduced nutrients input. In the scenario, flood irrigated cotton was converted to drip irrigated cotton, corn was using sprinkler irrigation and rice was using most improved irrigation system.

For example, baseline applications of phosphorus and nitrogen fertilizer to flood irrigated cotton were 70 kg P/ha and 190 kg N/ha, respectively. In contrast, under alternative fertilizer management scenarios, 78 kg N/ha was applied to drip irrigated cotton. Baseline irrigation demand for flood irrigated cotton was 1,573 mm/yr. Irrigation demand for alternative scenarios was lower than in baseline flood irrigated cotton. Irrigation demand for drip irrigated cotton was 840 mm/yr. Both are total demand including irrigation efficiencies.

SWAT simulations showed significant reductions in irrigation water demand in the alternative scenario relative to the baseline scenario. Under baseline flood irrigation of cotton, annual irrigation demand was 1,600 MCM/yr averaged over the 32 year climatic record simulated. Irrigated demand decreased by 53% to 855 MCM/yr when 1,018 sq km of flood irrigated cotton was converted to drip irrigated cotton. This represents a savings of 745 MCM/yr in water extracted from irrigation canals and groundwater wells. Similar results were found in Rice and Corn irrigated areas also. The water conserved would then be available for other downstream uses, including recharge of wetlands and replenishment of the Aral Sea.

As a result of reduced application of irrigation water in the alternative scenario, return flows of water from agricultural fields to nearby canals and streams was reduced slightly. More efficient irrigation and planting of crops that use water more efficiently reduced irrigation return flows by 0.5% relative to the baseline scenario.

More efficient irrigation also improved water quality relative to the baseline scenario. Losses of phosphorus from agricultural fields were reduced slightly by 0.8% in the alternative scenario, relative to baseline losses. Leaching losses of nitrate-nitrogen from agricultural fields was reduced by 4.6% in the alternative scenario, relative to baseline losses.

**Summary**

Farmer surveys were used along with Soil and Water Assessment Tool (SWAT) modeling to evaluate alternative irrigation practices and cropping systems that can conserve water in the Syr Darya watershed while maintaining farmer productivity.

Alternative practices evaluated include:

* Better irrigation water management (sprinkler and drip)
* Reduced fertilizer application

Impacts of alternative practices evaluated include:

* Improvements in water conservation through reduced irrigation demand from agricultural lands
* Improvements in water quality (reduced phosphorus, nitrogen and sediment losses from farms)

Farmer survey results indicated that up to 60% of the farmers in these villages were willing to change from flood irrigated cotton to alternative irrigation methods and cropping systems.

SWAT simulations were conducted using climatic data for the region from 2009-2013 along with baseline land use and crop management data obtained through remote sensing and farmer surveys, respectively. Two scenarios were simulated with SWAT. The first was a baseline simulation with existing land use and crop management practices that are dominated by flood irrigation of cotton, corn and rice. The second was an alternative scenario flood irrigated cotton was converted to drip irrigated cotton.

SWAT simulations showed significant reductions in irrigation water demand in the alternative scenario relative to the baseline scenario. Under baseline flood irrigation of cotton, annual irrigation demand was 1,600 MCM/yr averaged over the 32 year climatic record simulated. Irrigated demand decreased by 53% to 855 MCM/yr when 1018 sq km of flood irrigated cotton was converted to drip irrigated cotton. This represents a savings of 745 MCM/yr in water extracted from irrigation canals and groundwater wells. The water conserved would then be available for other downstream uses, including recharge of wetlands and replenishment of the Aral Sea.

More efficient irrigation also improved water quality relative to the baseline scenario. Losses of phosphorus from agricultural fields were reduced slightly by 0.8% in the alternative scenario, relative to baseline losses. Leaching losses of nitrate-nitrogen from agricultural fields was reduced by 4.6% in the alternative scenario, relative to baseline losses.