# Using Remote Sensing to Discover, Evaluate, and Prioritize Water Resource Improvement Projects and Their Watershed Effects in Southeast Afghanistan

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## ABSTRACT

Improved use of water resources in Afghanistan has become an important priority in U. S. Army operations. To further this, the Army Corps of Engineers, the U. S. Dept. of Agriculture, and the U. S. Geological Survey in conjunction with the U. S. Army's Task Force (TF)Yukon (4th Brigade Combat Team (Airborne), 25th Infantry Division) has undertaken a ground-breaking project to assess and prioritize numerous water resource improvement projects in SE Afghanistan. Conditions for completing traditional site-related review and planning are, to say the least, difficult. Our objective here was to identify and evaluate potential water resource projects in the southeast provinces using applied remote sensing science and technology. Sources of data included high-resolution satellite imagery, high-resolution elevation models, ground-truth from field personnel, existing spatial data and reports, and authors' experience in-country. Thousands of square kilometers were reviewed at scales up to 1:750 to identify and evaluate 295 potential water resource projects (storage dams, diversions, power generation, or upgrades to existing facilities, and watershed restoration). Each project was then prioritized using an industry-standard decision support model, integrating both engineering and watershed factors, such as sedimentation and stream system stability, cost indices, storage efficiency, benefiting agricultural lands, and environmental impacts. This study provided a systematic, detailed product to support field design, based on recognized expert evaluation. The report is now providing guidance to the Afghan ministries and coalition partners on developing water resource projects in a responsible and sustainable manner. In addition, the collected data are being used to scope potential water restoration projects and develop site plans. Utilizing remote sensing technology and expert personnel in this manner helped to maximize effectiveness of field investigation, sending ground personnel to only the most favorable sites for further evaluation, thereby reducing time on the ground in a difficult environment.

## INTRODUCTION

Southeast Afghanistan (Figure 1) is a region of water resource challenges. Though the study area is only seven percent of the country (ibid), it holds over 10% of the population. It is mountainous country, with an agrarian-based economy along narrow strips of cultivated land in the river valleys and broad depositional valleys (Figure 2). Most of the land is irrigated by small-scale, traditional methods controlled by small communities. The principal livestock are sheep, relying on large areas of relatively poor rangeland for production. Erosion and sedimentation are on-going and severe problems as are low security and remoteness. Intense, season-long grazing practices exacerbate many of the water resource problems in the region. The area has some of the largest forested areas in Afghanistan (ibid), an important economic resource, but deforestation has also contributed to watershed erosion problems.


Figure 1. Study Area (44,700 sq. km)

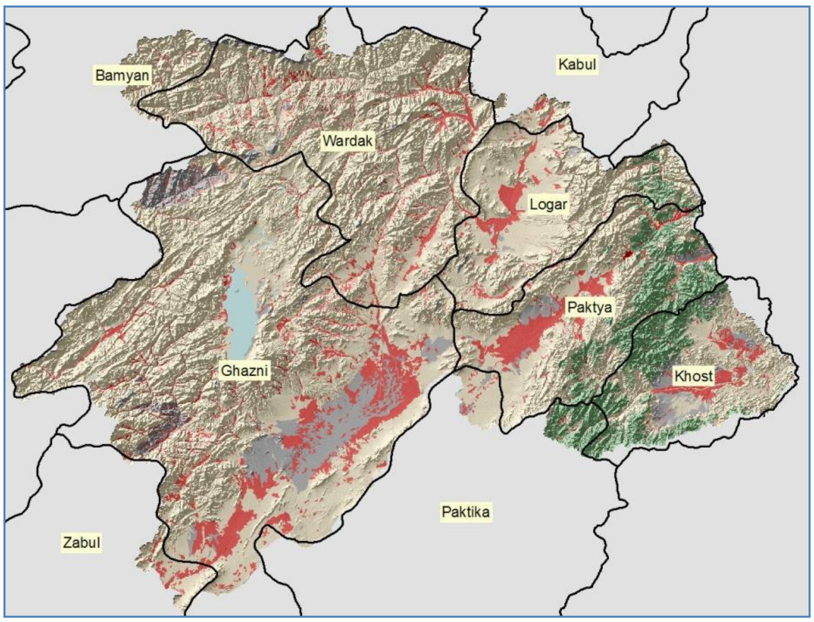


Figure 2. Land Cover and Landforms in the Study Area: Light Brown is rangeland; Green is forest; Red is irrigated agriculture; Gray is bare soil and rock; Light blue is water; Mountainous areas are shown in relief. Labels are Provinces.

Annual potential evaporation from vegetation and land surface greatly exceeds precipitation. Therefore farmers generally rely on irrigation for their crops and groundwater for safe household water supplies. The purpose of this assessment was to discover and evaluate potential water resource improvement projects to assist those agricultural efforts.

## METHODS

Any comprehensive planning process for water resources assessment requires data. Precipitation patterns and quantities, groundwater resources, and sediment all affect resource development potential. Local landforms and physical watershed configuration, local surficial and bedrock geology, upland conditions, local existing development, potential downstream benefits, and environmental impacts all affect project location. Watershed condition and potential for contributing sediment affect both long and medium term project success, as well as affecting short-term construction costs. Because the large study area was comprehensively reviewed at a large scale, both for canvassing and detailed evaluation and accurate location of each proposed site, an immense amount of spatial data was required, in addition to the authors' experience in-country.

**Raster Data.** This study was based on the use of remotely sensed data gathered by satellites and aircraft. A significant part of this water resource assessment was the effort required to locate, acquire and process those data. Approximately 1.5 TB of imagery and elevation data was processed and delivered to TF Yukon and the analysis team. The data was collected with the intent of being made available for future or more detailed studies of the region.

QuickBird-2 and Ikonos satellite images were the primary commercial imagery sources were acquired through the National Geospatial-Intelligence Agency (NGA) from DigitalGlobe, Inc., and GeoEye, Inc. QuickBird imagery was delivered as a pan-sharpened, plane-rectified, 0.60 meter, 4-band image file. The QuickBird images provide both a natural color and near-infrared false color composite of the ground surface. The near-infrared imagery was used in the evaluation of vegetation and soil conditions. Every QuickBird image was orthorectified to remove the terrain distortions and projected to WGS84 UTM Zone 42 North by GIS Staff at the USACE Wilmington District. A subsequent step of rescaling from a 16-bit to an 8-bit file was performed to reduce the file sizes.

LANDSAT satellite imagery was used to evaluate changes in vegetation over time and evaluate the soil erosion potential of the watershed. 1999 and 2008 were the years that change was evaluated. The images were processed and a vegetation change algorithm was run to highlight change on each pair.

Shuttle Radar Topographic Mission (SRTM) elevation data was acquired from NGA. SRTM is a level 2 product with elevation posts every arc second (roughly 30 meters). In addition to the SRTM data, a higher resolution digital elevation model (DEM) was used. This dataset was collected with IFSAR (Interferometric Synthetic Aperture Radar) onboard an aircraft and has a 5 m post spacing DEM. The 30 m SRTM DEM was used to delineate and create GIS polygon shapefiles of the major watersheds (sub-basins) draining the five province study area. The watershed shapefiles were then used to cut the higher resolution 5 m DEM into more manageable size DEMs. Arc Hydro Tools in ARCMAP version 9.3 (ESRI, Inc) were used to fill sinks in the 5m DEM, delineate sub-basins, streamlines along with slopes and other attributes. Watersheds for the evaluated water resource project sites were delineated using the 5 m DEM.

**Vector Data.** Vector spatial data required in analysis and in preparing maps were obtained from the Afghanistan Information Management Services (AIMS), USGS, USDA, and numerous legacy publications. Land cover for the study area was extracted from a generalized land cover spatial layer for Afghanistan generated by the United Nations in 2001 and 2002 from LANDSAT imagery.

Geologic spatial data at a medium scale (usable down to 1:24,000) was obtained. It was based on geologic mapping done by the Soviets, with nomenclature modified by the USGS. General soil spatial data were available for the entire country but were adequate only for characterizing basic soil temperature and moisture at a Sub-basin scale However, detailed legacy data were geo-referenced to improve its quality in some places.

Once project locations were selected, new shapefiles were created of contributing watersheds, project sites, elevation contours, inundation contours, streamlines, and other supporting hydrologic parameters.

**Precipitation Estimates**. Southeast Afghanistan has an arid to semi-arid climate. Annual precipitation ranges from under 200 mm in western Ghazni Province to over 400 mm in Khost. Most of the precipitation occurs during winter but the eastern provinces of Khost and Paktya can receive 100 mm of rainfall during the summer monsoons, (Figure 3). Annual potential evapotranspiration (ET) greatly exceeds precipitation for the entire study area making most crops reliant on irrigation. The annual ET rate at Gardez in Paktya is 1,300 mm. Historic precipitation data for 15 stations were identified in the study region with an average record of 15 complete years. The major drawback was that all available data were monthly totals dating from 1950 to 1980, since daily records have been lost. Organizing the historic data was a significant task in that none of the five different sources of data were temporally complete. Computed gridded climate data missed the monsoon events and therefore were not used in the analysis.

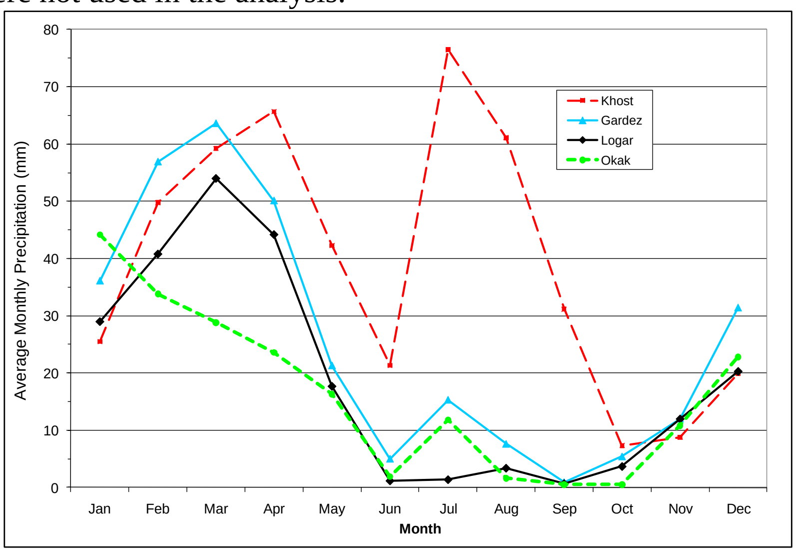


Figure 3. Annual Precipitation in Southeast Afghanistan

**Streamflow Estimates.** Streamflow gage records in Afghanistan cease in 1980 with the Soviet invasion and new gages are currently being installed. The USGS was tasked with obtaining and processing into a publically accessible database all historic streamflow data (USGS, 2009). Daily average records from 35 gaging stations in the study region were used in the analysis. The length of records ranged from two to 19 years dating from 1940 to 1980.

The effects of snowmelt and monsoon can be seen in the hydrographs of the Helmand River and Shamal Rivers in Figure 4. The Helmand watershed is in the mountainous region on the western side of the study area and Shamal is at a lower elevation bordering Pakistan. The Shamal has a peak two months earlier than the

Helmand and has a second peak associated with monsoon events. The Helmand has a higher baseflow. The impacts of irrigation withdraws was noticeable as many streams had decreasing discharge as they flowed downstream. In addition, in arid regions declining flows are common along low gradient, alluvial stream reaches due to infiltration into the streambed. The hydrographs also indicated that groundwater springs were contributing flow to streams in the upper watersheds.

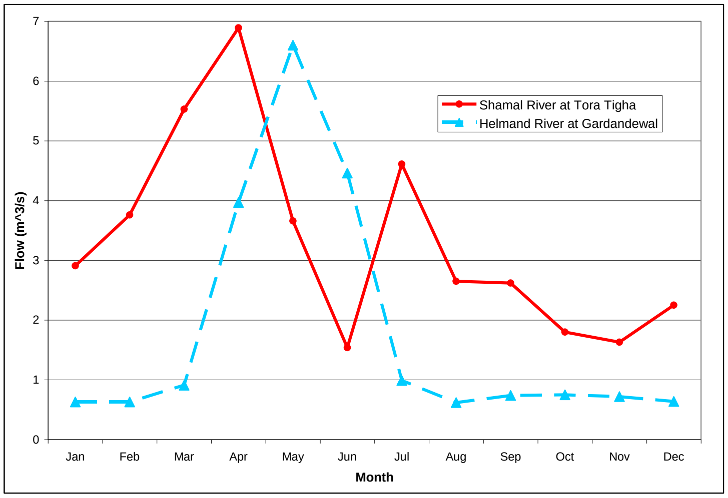


Figure 4.. Monsoon and Snowmelt Impacts

**Water Budget Estimates.** To properly size an irrigation storage dam or determine the generation potential of a micro-hydropower project, a stream's annual water budget from the watershed must be known. The available water budget was also used in the ranking of project sites in the decision support model. Calculating a water budget was challenging due to the lack of precipitation and stream gage data and by the naturally variable climatic and landscape characteristics of Afghanistan.

The development of computer runoff models was not practical because of the large number of project sites evaluated and short assessment timeframe. Developing watershed unit hydrographs to calibrate models would not have been possible because of the lack of hourly or daily watershed precipitation data to match the corresponding daily streamflow data. To estimate runoff at the project sites a simple correlation was developed between streamgage records and precipitation at 27 gage locations in the study region. This correlation or runoff ratio was calculated in monthly time steps in $m^3$/mm/ha. This runoff ratio was then applied to a project watershed that had similar characteristics as the watershed from which it was derived. The larger watersheds with numerous upstream irrigation diversions had runoff ratios below 1 $m^3$/mm/ha. The smaller watersheds in the higher elevations had ratios over 4 $m^3$/mm/ha showing the influence of the snowpack and groundwater springs. More detailed hydrologic analysis will be carried out at the project sites selected for design to ensure a safe spillway design that will pass flood flows.

**Irrigation Storage Dams Analysis.** Location of potential projects for irrigation storage, hydropower, and diversion projects was completed by a detailed canvass of landscape data, existing publications, and local information. Each project was then analyzed for potential.

Irrigation storage dams in Afghanistan are used to capture runoff from spring rains and snowmelt and to regulate releases for summer irrigation when precipitation is scarce. In monsoon influenced regions, the dams capture runoff from the brief, heavy downpours. Potential irrigation storage dam locations were identified from previous studies, inquires to Afghan Ministries and by canvassing satellite imagery with elevation contours. Locations were judged good candidates where a narrow valley minimized dam width and construction cost.

Engineering properties calculated at each dam site included watershed area, stage-storage curves, dam dimensions, construction volume, reservoir inundation maps, annual water budgets and irrigation service area. Stage-storage curves were calculated in 1.0 m increments with cumulative storage volume from the base to the dam crest using the 5-m DEM.

An important factor in evaluating the benefit of a dam is the crop irrigation water demands. In a simplifying effort, winter wheat and maize were selected as the representative crops for irrigation scheduling and volume demands. A total seasonal demand of 1000 mm (39.4 in) was used for both crops beginning the 1$^{st}$ of March and ending August 31$^{st}$. The dams were designed to hold and regulate the release of enough water to irrigate the crops to a depth of 167 mm each month. A spreadsheet was developed for each dam to determine the potential area that could be irrigated. Of the total amount of watershed runoff that enters the reservoir only about 55% is utilized by crops. The majority of those losses are from the inefficient distribution system and irrigation practices. In addition, the main factors driving this were; watershed area, precipitation, dam storage, the runoff ratio and crop demand.

The irrigation storage dams were sized in two ways. The first method was to maximize the storage volume to hold as much runoff as possible while at the same time subtracting monthly irrigation demands and other losses. The goal of the "maximized" dam was to have enough water to irrigate wheat in spring and maize through the end of August. These dams tended to be very large and were not feasible at many locations.

The second method was to evaluate the storage volume provided by a set 12, 8 and 5 m high dam. The 5 and 8 m high dam are the typical for irrigation storage dams in Afghanistan. These dams are capable of supplying water to irrigate winter wheat in the spring and in some wetter years, supply water for the first planting of maize. The service area was determined by increasing that area until the reservoir went dry in June. Optimizing the dam height based on construction cost, long term maintenance and economic benefits will be addressed during design.

**Hydropower Project Analysis.** Potential hydropower sites in Afghanistan are limited more by available streamflow than by suitable topography. The steep stream slopes and narrow river gorges in Afghanistan provide excellent elevation change and driving head for turbines to produce electricity. It is the lack of steady, year round baseflow at most sites that is the restraint on hydropower. The evaluation in this assessment is focused on run-of-river micro and mini-hydropower with a generating capacity between100 kW and 1MW.

The run-of-river projects use a small weir to divert streamflow into a headrace channel that flows parallel to the stream but at a milder slope, increasing the elevation difference between the headrace and streambed. The headrace channel ends at the penstock which conveys water down to the hydropower turbines and back into the stream. Hydropower at the irrigation storage dams was not recommended because of timing conflicts between irrigation and power demand. Run-of-river hydropower sites were identified by reviewing the satellite images and elevation contours. Streamflow was determined by using the runoff ratio method used in the irrigation dams and streamflow statistics of a nearby gage as calculated by the USGS.

A good hydropower site had to have a stream with a steep slope to provide driving head for the turbines. The valley side slopes also needed to be steep to keep the penstock length short and reduce headloss. The watershed had to be large enough to provide sufficient flow with little irrigation diversions upstream. The hydropower site also should be near settlements to keep the cost of transmission and power losses low.

**Irrigation Diversion Analysis.** Irrigation diversions are structures used to redirect flow from a stream and into an irrigation network of canals and ditches. Traditional irrigation diversions in Afghanistan consist of a dam less than 1 m high. These traditional diversions wash out during floods and are rebuilt. More permanent concrete structures have been built across streams to divert water into more engineered irrigation networks. Both types of diversion structures utilize water elevation differences in the range of centimeters to divert flow and transport to the fields. Potential sites were identified during the irrigation storage dam review.

**Project Watershed Characterization**. Once a potential project site was selected, and its associated watershed delineated, estimates were made to index present condition in terms of what might affect streamflow and sedimentation. Both detachment and transport processes were modeled. Degree of surface detachment and local transport were estimated by active upland gully erosion and recent deforestation. Major transport processes were estimated by rating stream characteristics.

For upland erosion an imagery survey of steeply sloping lands indicated the predominant visible surface processes are gully erosion on otherwise stable-appearing upland slopes and stream bank erosion. Other data show universal intensive grazing with attendant sheet and rill erosion contributes significantly to poor watershed conditions, but is not measurable via imagery without extensive ground sampling. There is probably a correlation between high gully erosion and high sheet erosion, but not necessarily between low gully erosion and low sheet erosion. Hence we have probably under-represented actual erosion in certain soil types.

To estimate active upland erosion we created 12 geologic groups from the 60 groups in the geologic spatial layer, based on relative uniformity of rock type composition. Each group was sampled randomly across the footprint of all project watersheds with 50 sites of 100 m radius at a scale of 1:900. Within each circular plot, presence or absence of gully erosion was described (Figure 5).

The 50 samples were tabulated to estimate % eroding land in each rock group. Using the rock group spatial data, the proportion of each group in each project watershed was used to create a weighted average of active gully erosion for each project watershed.

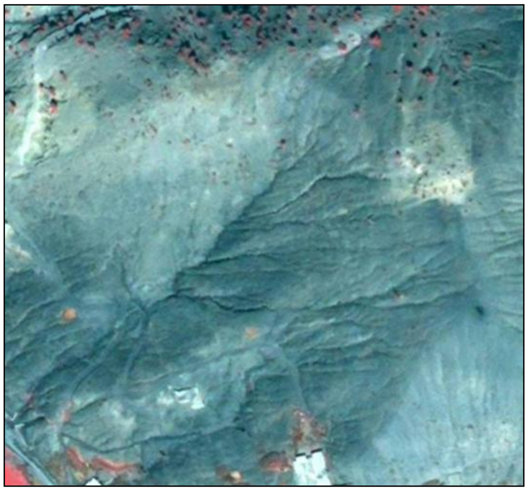

Figure 5.  Plot Sample - Active Gully Erosion

Deforestation also contributes to increased sediment loading in project watersheds.  This study used LANDSAT images at two dates and a U. S. Forest Service classification tool to estimate vegetation change developed initially for wildfire mapping.  The model is based on a Normalized Differential Vegetation Index (NDVI).  It was ground-verified using a canvass of CIR (Color Infrared) QuickBird satellite imagery. Initial forested area used for the LANDSAT image acquisition footprint was based on a LANDSAT classification of land use.. It is about 70% accurate based on CIR imagery interpretation, classifying more land as forested than is probable. It was judged sufficiently precise for limiting the extent of analysis.

The model results show both wildfires and logging occurring in the last nine years.  Figures 6 (left) shows an example area in the western part of the Khost province.  Yellow and red indicates significant vegetation change over the time period.  This change is almost certainly due to extensive logging, based on interpretation of the CIR imagery (Figure 6 right).  Note the regular boundaries, and apparent skid roads.  Deforestation was tabulated by each project watershed.

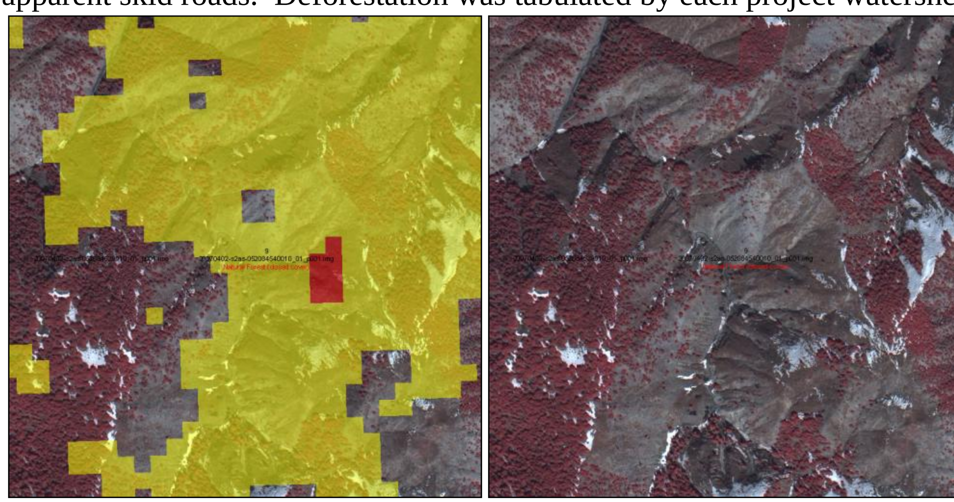

Figure 6.  Deforestation Estimation – Reflectance Change and Ground Truth

Stream system stability influences the feasibility of dam construction and maintenance.  The kinds and density of stream drainage networks help indicate the character of a watershed as well as potential for uses of the transported surface waters. All stream channels digitized for the engineering portion of this project were reviewed and attributed.

Each stream reach was reviewed at a scale of 1:24,000 with color-infrared satellite imagery. The same imagery at a scale of 1:2,400 or larger was used to determine bank vegetation, character of flood plain, presence of bedrock banks, live water, and other characteristics at representative points within the reach. Seven classes were developed based on the above criteria, developed from a reconnaissance of the entire watershed study area at a scale of 1:24,000, and supplemented as new kinds of channel systems were identified.

The seven classes were merged to "stable" and "unstable" systems. Unstable systems have high-sedimentation rates and highly variable flow. "Stable" systems have relatively lower rates and more stable flow. Results were tabulated by project watershed, recognizing the significant overlap in many watersheds.

Site stability influences both dam design and maintenance. Dams on large, unstable streams are likely have high rates of sedimentation, requiring frequent dredging, and have potentially severe problems in terms of reservoir maintenance and damage from sediment. See Figure 7 (left) for an example of a recently-constructed dam in Afghanistan after only three years of use built on a large unstable stream. Projects within 300 m of a rated unstable stream were flagged.


Figure 7. Reservoir Filling on a Large, Unstable Stream (Oosterkamp) and Inundation.

Not only do the watershed conditions described above affect success at the project site, but the project itself will also affect its environment in both positive and negative ways. An index of negative impacts was created based on the probable inundation of dwellings (to estimate population effects) and bridges (a measure of infrastructure effects). Benefits include potential irrigated land.

An estimate of the number of dwellings and bridges inundated was made for potential pools representing four potential dam heights. Dwellings and bridges within each pool's perimeter were digitized as points at 1:1,500 scale (Figure 7 right) and tabulated for each pool polygon.

Downstream benefits are related to agricultural production. Because settlement spatial data were not accurate enough for an estimate of affected population, a benefit index was created of irrigated land. All irrigated land visible at a scale of 1:1,500 was digitized on the CIR imagery to a buffer distance of 9 km *downstream only from the project location.* This was considered a reasonable maximum limit for irrigation benefits. Data were tabulated by project watershed.

**The Decision Support Model.** Hundreds of preliminary project sites for this assessment were selected through the canvassing process. Each location has characteristics favorable for dam construction and reservoir development, watersheds have potential for sufficient delivery, and existing agricultural lands are within a reasonable distance.

After this large initial selection of feasible sites was complete, and each project analyzed, the evaluation process became more complex. Some projects have better combinations of characteristics than do others. For example, two otherwise promising projects may have very different construction costs, which will influence their prioritization. Also, the degree to which local economies are affected may be quite different, depending on the relationship between impacts and benefits. Finally, some parameters that may affect project effectiveness (such as watershed condition) were not available for the initial canvass for locations.

A decision support model was developed to help rate the project proposals. The advantages of using it include systematic and consistent rating for each of many projects, repeatability and documentation, the ability to modify the rating system as circumstances change, and the ability to include subjective weights to modify the objective data in the rating system. The process used here is based on a decision support system using the Simple Multi Attribute Rating Technique (SMART) implemented through software from Infoharvest, Inc.

Important features in the irrigation storage project evaluation include costs and efficiency, potential benefits and impacts, and longevity expressed through watershed condition (Figure 8). These criteria come from the irrigation storage dam analysis and watershed characterization described above. Each criterion was weighted by its relative importance to project success, shown in Figure 8 prefixed to each weighting factor. These were based on expert and client review.

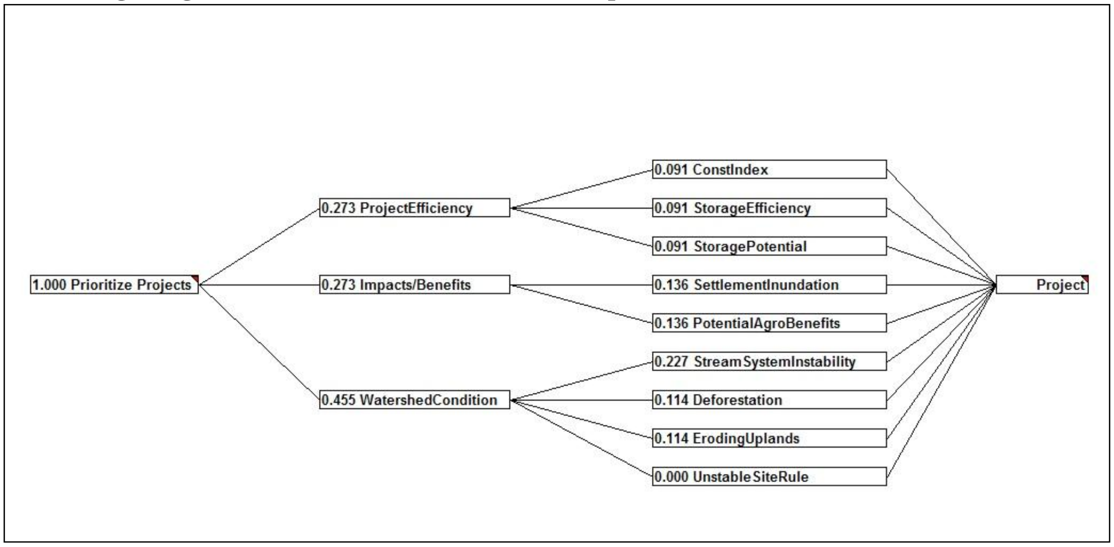


Figure 8. Decision Model Hierarchy for Irrigation Dam Ratings

The decision support model process was not designed to be used on its own. Final project selection was also based on other factors, e.g. security, administrative structure, or policy. However, it did help define many of the important criteria so those other factors can be overlaid on a base of structured thinking.

## RESULTS

**Irrigation Storage Dams.** Of the 295 total projects all 159 irrigation dam sites were evaluated using the formal decision model described above. However, we discovered this level of analysis was not possible for the 120 hydropower dams and 110 irrigation diversion structures. Therefore, we resorted to a less-formal narrative rating for those projects. Note many projects had multiple potential functions, hence storage dams, diversions, and hydropower projects do not add to the 295 total.

Figure 9 shows model results for irrigation storage dams. Most promising projects appear to be in the northern provinces. Watershed condition is generally higher in those areas, with relatively poor conditions in the southeast.

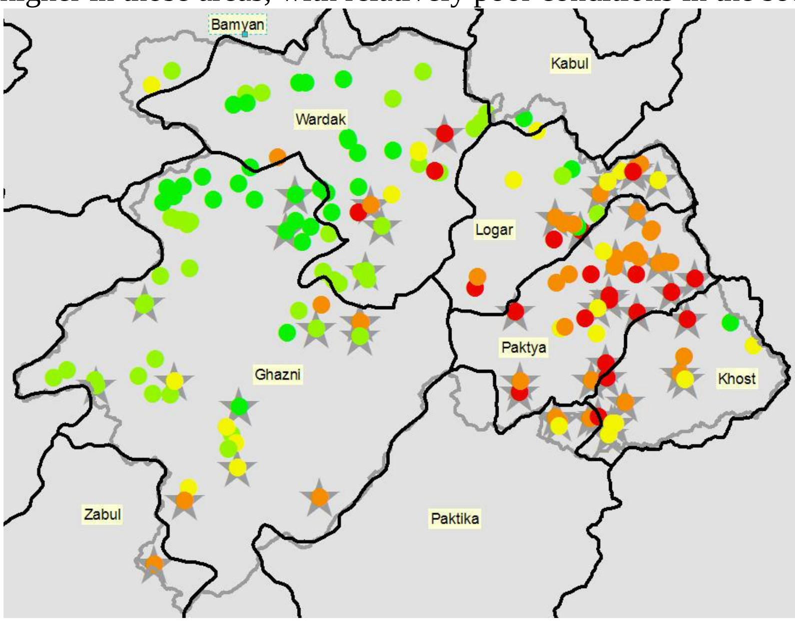


Figure 9. All 12m Dam Irrigation Storage Dam Ratings. **Higher ratings are in shades of green and lower ratings in shades of red. Project site instability is shown in gray stars underlying the rating symbols. Labels are province names.**

*Considerable interpretation is used in addition to that provided by the decision support model.* The report appendix submitted to TF Yukon included reservoir inundation maps with satellite imagery of each project site. The maps were used to identify in more detail impacted households, farmland and roadways. A sample inundation map of a dam in Khost is provided in Figure 10. The appendix also includes stage-storage graphs and tables that proved valuable in comparing dam sites.

In terms of irrigation storage dams, the terrain and condition of the watersheds in southeast Afghanistan are generally unfavorable. Analysis showed the majority of the sites had little reservoir storage potential or the dam's watershed condition presented serious sedimentation issues. The mountainous terrain in Afghanistan results in streams with very steep gradients exceeding 5%. Therefore, the reservoirs have little storage per height of dam. Many watersheds had large areas of relatively-high active gully erosion and deforestation with unstable stream systems. Some sites, though favorable from an engineering standpoint, were located on wide, unstable streams that present significant challenges in design, implementation, and maintenance (Figure 7 left).

Even with the generally unfavorable terrain, some good dam sites were identified. Five top dam sites were identified with locations were so exceptional that a even a 5 to 12 m high dam would not take full advantage of the storage potential and agricultural benefits.

Available streamflow also influenced recommendations. The tributaries in the upper Helmand River watershed in the Ghazni Province have sufficient year-round baseflow that water storage is not generally needed. Diversion structures were recommended instead of storage dams to irrigate crops. The tributaries in southwestern Ghazni contain so little flow with very little existing agriculture that no dams were recommended in this area.

Any proposed dam in Afghanistan would have to contend with high sediment loads but some regions of the study area were worse than others. The landscapes of Khost and Paktya have naturally erosive soils, and the steep stream gradients in this region make managing the sediment more difficult. Those gradients resulted in reservoirs with very little storage to hold accumulated sediment. It was recommended that TF Yukon consult with international experts on appropriate outlet designs to encourage sediment passage through dams.

Some of the dam sites evaluated but not recommended had been previously proposed by local government officials. Many of these sites appear to have good engineering properties on the ground but further analysis revealed the sites had very little storage potential or a watershed too small to justify construction. The assessment provided the engineering data to work with the local government in finding better locations or more appropriate agricultural improvement alternatives.

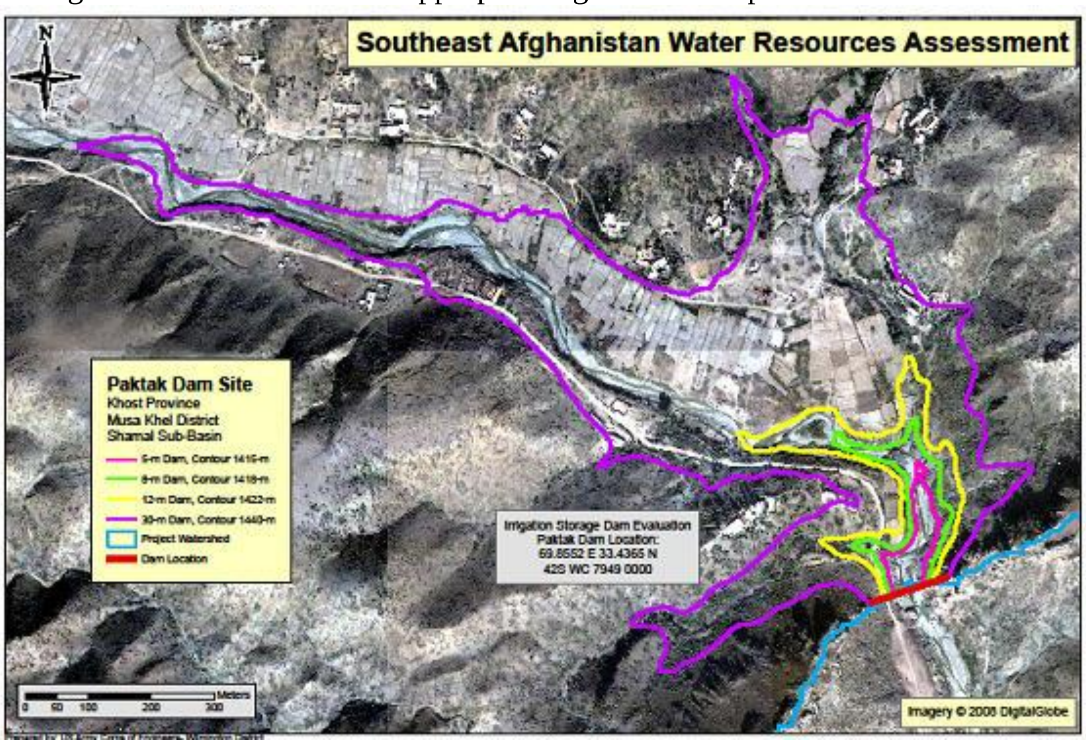


Figure 10. Reservoir Inundation Map, Paktak Dam, Khost

Three projects are now being evaluated for further development by Afghan and coalition personnel.

**Hydropower.** Hydropower potential in southeast Afghanistan is limited more by the lack of available streamflow than from suitable terrain. The steep streams in the study area offer large elevation changes over short distances providing excellent driving head for hydropower turbines. The issue was that most of the streams are dry for many months of the year and irrigation demands divert large amounts of water out of the streams. Another issue was that many promising locations were far from population centers.

Hydropower was evaluated at 120 locations. The report appendix contains satellite images of each project site and with planning layout of the weir, headrace, penstock and powerhouse. Detailed analysis of each of the sites is provided in the appendix with power generation in monthly time steps.

The best hydropower locations were located in northern Ghazni Province on the Helmand River. The mountainous watershed provided year round stream baseflow and the steep stream slopes provided driving head for the turbines. A summary of the sites evaluated on the Helmand is provided in Table 1. Coordinates are provided in both Lat/Long and in military grid (MGRS). Actual power provided will be less and depends on the size and number of generator units in the powerhouse and the available streamflow. With the large available flow from the Helmand River, the Sinak headrace channel could also serve as an irrigation diversion channel. Before any hydropower project is pursued, local knowledge of the streamflow characteristics should be obtained and agriculture impacts determined.

Table 1. Hydropower Sites Evaluated on the Upper Helmand River

| Name | Longitude | Latitude | MGRS | Headrace Length | Potential Head | Generation Potential | |
|---|---|---|---|---|---|---|---|
| | | | | (m) | (m) | (kW) | (kW-hr/yr) |
| Zarkharid #1 | 68.2641 | 34.5074 | 42S VD 3243 1866 | 1,540 | 13.8 | 267 | 2,349,642 |
| Zarkharid #2 | 68.2396 | 34.5127 | 42S VD 3019 1926 | 1,050 | 20.8 | 223 | 1,963,241 |
| Qala-i-Haydar | 68.1715 | 34.5839 | 42S VD 2402 7210 | 1,040 | 17.8 | 121 | 1,061,689 |
| Dahan-e Abdullah | 68.0839 | 34.4933 | 42S VD 1589 7239 | 2,855 | 23.6 | 806 | 7,082,643 |
| Sinak | 67.8089 | 34.4137 | 42S UD 9054 0866 | 4,813 | 24.7 | 1,529 | 13,441,206 |
| Panjasya | 68.0539 | 34.4946 | 42S VD 1314 7402 | 1,950 | 6.2 | 216 | 1,899,201 |
| Abbas Koshteh | 67.6401 | 34.3353 | 42S UD 7490 0017 | 745 | 25.0 | 96 | 840,609 |
| Gardandeh | 67.7161 | 34.4108 | 42S UD 8222 0795 | 480 | 55.1 | 682 | 5,991,393 |
| Otopur | 68.1532 | 34.5996 | 42S VD 2235 2896 | 1,155 | 35.4 | 223 | 1,963,241 |
| Khuskdana | 67.8785 | 34.4530 | 42S UD 9698 1295 | 1,410 | 31.4 | 120 | 1,058,384 |
| Shinah | 67.8049 | 34.4492 | 42S UD 9022 1261 | 1,495 | 37.0 | 164 | 1,438,629 |

**Irrigation Diversions.** It was not possible to evaluate irrigation diversion structures using remote sensing. The water elevation differences used to drive the diverted flow are in the range of a few centimeters. The vertical accuracy of the digital elevation model can be as much as +/- 3.0 m but is usually within +/- 0.5 m. More detailed analysis was possible with the irrigation storage dams and hydropower projects because those dam heights and the elevation differences were larger than those tolerances.

Even with the limits of the remote sensing dataset, 110 potential diversion locations were identified. These locations were deemed to have good potential based on available streamflow, stream configuration and downstream terrain favorable to agriculture. These sites require further investigation on the ground to confirm suitable soil types. Diversion structures along the major rivers tended to be better sites than those on the tributary streams. The major river sites tended to have more stable streambeds, year-round baseflow and existing cultivation. The traditional temporary rock weir is more appropriate on the tributary streams.

**Groundwater Resources.** The lack of available geohydrologic data and knowledge concerning Afghanistan's aquifers can make utilizing groundwater resources in the study area a risky endeavor. As part of this assessment, the USGS conducted an extensive data gathering effort and appraisal to determine the best technique in evaluating groundwater resources. They collected over 9,000 records and prepared a detailed strategy to better quantify the region's aquifer capacity.

**Sedimentation.** One of the most important issues to consider when proposing a water resource project in Afghanistan is sediment management. The swift moving streams draining barren watersheds carry a high amount of suspended sediment and moving bedload (Figure 7 left). Limited sediment yield data available from engineering studies showed values ranging from 200 to 250 tonnes/sq km/year. A rough estimate of the time for the reservoir to be half full of sediment was determined based on these estimates, and used with the stream stability estimates.

**Watershed Restoration.** As in the water resource projects evaluated above, potential for watershed restoration was evaluated both in a strategic and tactical manner. Restoration potential is influenced by the condition of the watershed stream system, overall active erosion, and degree of deforestation in forested areas. Watersheds with favorable conditions may be stronger candidates for resource allocation. A higher proportion of actively-eroding upland provides more opportunities for upland restoration and more potential for reforestation projects at higher elevations. A relatively stable stream system increases the opportunities for streambank restoration projects, and increases chances of their success. Finally, local population and existing agricultural infrastructure make any project more beneficial. Watersheds with these characteristics are the likely places where watershed restoration would be successful. On all watersheds better range management practices could also reduce wide-spread sheet and rill erosion.

To remotely prioritize the 295 proposed project watersheds we developed a structured decision support model, based on data gathered in the assessment and the irrigation storage decision model described above. Since it is based on consistently measured watershed properties, it can be used to help guide watershed restoration efforts on the ground.

Ratings are based on a decision support model with four criteria (stream stability, deforestation, erosion, and potential benefits). For this model each of the main criteria are weighted equally. Best opportunities appear to be in Khost and Logar provinces.

These ratings were also used to scope three potential watershed restoration projects and develop site-specific restoration plans. The highly-detailed imagery and elevation model were used to canvass areas recommended by the TF for likely locations for watershed restoration projects; provide systematic site plans for restoration projects at scales down to 1:1,000; and with limited ground support, provide quantities and project specifications.

## CONCLUSIONS

This study was based on analysis of high-resolution satellite images, digital elevation models, available spatial data, assistance of experts familiar with the region, the authors' in-country experience, observations by on-site personnel, and publications. We were able to investigate the hydrologic, social, land use, and geologic patterns of southeast Afghanistan without the expense and effort of actually being on the ground in an un-secured environment. However, we ran into significant limitations, e.g. the unwieldy size of the dataset, the large effort required to process the data, and the limitations of analysis scale.

Though Afghanistan is a land of agricultural challenges, there are many areas with high-quality watersheds, high-potential projects, and large potential benefits to people. The trick is to find them. In any intelligence-gathering operation, sometimes we see the forest, sometimes only the trees. This assessment provides benefits on both ends of that spectrum. The first is the use of a structured, standardized, and area-wide planning tool to make good strategic decisions over the study area. The second is direct and clear recommendations on a specific site basis, to guide tactical decisions and produce further work on the ground. Potential projects both in water resources and in watershed restoration are explicitly located, as are their effects on the population, irrigation potential, and the environment. But their location was the result of a systematic, consistent, and review of the entire study area, not a spot sample of a few areas.

And even those spatially-explicit recommendations are not as significant as the *analysis* behind them. It is based on specific hydraulic, hydrologic, and watershed *data*. Anyone can review the analysis and those data and see the "Why" behind them, and their development using our remote sensing tools.

But that analysis is not so important as the integrated *approach* used here to assess the problem. Criteria for any potential project included not only project-specific factors (such as storage capacity) but also watershed factors (such as sedimentation potential) to make a truly integrated assessment. Also, those criteria were chosen to represent physical, environmental, and technical factors. However, politics, policy, programs, security, logistics, and tribal relationships affect any decision as least as much. We consciously largely left those factors out of our analysis. By leaving them out, resource decision makers can be more confident that those factors do not confound the results.

And finally, not even that is as important as the *perspective* on how to approach development in developing countries. In no way do the recommendations, results, methods, or modeling match the standards of the developed world. There are significant limitations. But we have attempted to make the best of the situation, to make some progress in understanding the ecosystems and needs of the people of Afghanistan, to make some headway on the ground, and to make a difference in an imperfect environment.

This assessment will not provide everything wanted, or even everything needed. Ground evaluation is essential for any further project development. But it is a start. It can be the progenitor of long term planning and short-term project development that has been missing until now.