Appendix V-1
V. Water Use in the Clark Fork and Kootenai River Basin

1. Methods for Estimating Water Use for State Water Plan

- Irrigated Agriculture Acreage

Introduction

There are a number of sources of information on irrigated acreage in the Clark Fork and Kootenai River Basins. The DNRC Water Rights Database contains a variety of information on water rights claims and permits with irrigation as the use and each of these is associated with an irrigated acreage. This database is based on information established to provide the water-right holder with a legal entitlement to a maximum rate of water diversion associated with a particular amount and location of irrigated acreage.

While this information serves the intended purpose well, it is not adequate for an inventory of consumptive use for several reasons. First, the data provides information on the maximum amount of use that would occur (for example, full-service irrigation on all acres) in a year that is not constrained by physical water availability—in other words no water shortages would occur throughout the irrigation season; second, not all drainages in the Clark Fork and Kootenai Basins have been adjudicated and the final amounts of diversion rate and acreage determined; third, a variety of logistical and economic factors influence how much irrigation occurs in any given year.

To account for these potential limitations, a process was developed to map irrigated acreage in the Clark Fork and Kootenai Basins (and across the state) for the purpose of providing an estimate of consumptive use for a typical year. The year 2007 was selected because of water-supply conditions and the availability of supporting information, including the number of cloud-free Landsat scenes.

Several sources of data that were used to map existing irrigation in a Geographic Information System.

DOR FLU data:
The Montana Deportment of Revenue has a GIS coverage of land use that evaluates irrigated lands for property taxes. This data (FLU) is state wide and includes data from the RWRCC and DNRC's evaluation of existing uses. The FLU data has large parcel data that has limited value for individual field evaluation. Because it is important to have unique irrigated parcels for the evaluation of consumptive water use , the FLU coverage was intersected with the BLM's GCDB (legal land description) coverage to obtain a FLU coverage that has a maximum parcel size of the GCDB data. This GIS file was then used to select those parcels that do not include the other DNRC data (described below).

DNRC Water-Rights Mapper data:
The DNRC has a GIS program that is used by its claims examiners to evaluate SB76 filed claims in the Montana water-rights adjudication process. This evaluation is based on 1980 imagery and includes areas that are not included in the previous data. The data that is not included is added to the data set.

Montana Water Resource Survey (WRS):

The Montana Water Resources Surveys are a comprehensive county by county assessment of Montana's historical water use. This data was collected and published from 1943 thru 1965 by the State Engineers Office and from 1966 thru 1971 by the Water Conservation Board (both predecessors of the current DNRC). Most published surveys consist primarily of two parts: Part I; a known historical account of water use in the county, and Part II; survey maps of current water use at the time of publishing. The survey data was derived from courthouse records in conjunction with individual contacts with landowners, field investigations and aerial photography. Data collected from various other agencies and resources were also used. This information, while dated, is an excellent and detailed source of information on irrigated acreage at a point in time and was integrated with the DOR FLU, DNRC Water Rights Mapper, and other information (for example data produced by the Reserved Water Rights Compact Commission; mapping prepared by consultants for special projects.

Final Irrigation GIS Data.

All of the data sets were filtered to eliminate polygons less than 5.0 acre in size and an ESRI shapefile was produced with the following attribute:
:
Irr_id: unique numbers for each polygon in the coverage. This id number can be used to link to the original data sets.
Proj: this attribute describes which data set was used for the polygon.
Class: HKM's irrigation evaluation.
Unit: RWRCC unit that was used.
Crop: crop type if available in the base data.
Sys: type of irrigation system if available in base data.
Acres: polygon size in acres.
Basin: Water Court basin id.
Irrcode: WRS code (this code can be used to identify irrigation district lands vs. private lands).

- Estimation of Consumptive Use Associated with GIS-Mapped Irrigated Acreage

The Idaho Department of Water Resources, in Cooperation with agricultural engineers at the University of Idaho Kimberly Research and Extension Center, and NASA, have developed the METRIC method for estimating evapotranspiration (ET) and consumptive use from Landsat satellite imagery and ground-based weather station data. This information is very accurate and has been collected and analyzed to provide consumptive use information in the Flathead Valley to support estimates of consumptive use for the CSKT Compact, hydrologic modeling in the Smith River basin, and in the Wyoming portions of the Powder and Tongue River basins to support Montana's U.S. Supreme Court litigation with Wyoming. Use of METRIC requires considerable planning, on-the-ground data collection, and was beyond the scope of the State's current water planning effort (see the website below for more information on METRIC). The METRIC method, and the one developed for the State Water Plan, are based on the fact that ET consumes energy and Landsat satellite sensors can measure that energy use which can then be translated into an amount of water used by vegetation.

http://www.kimberly.uidaho.edu/water/

DNRC Water Resources Division agricultural engineers, GIS analysts, and hydrologists developed a less data intensive method, than METRIC, for estimating statewide ET and consumptive use from irrigated acreage. This procedure falls within a class of methods referred to as vegetation-index methods—although the process does incorporate the Landsat thermal band (band 6) to help overcome some of the limitations of pure vegetation-index methods. The method relies on processing of weather station data (primarily the USBR's Hydromet stations) and Landsat 5 and 7 scenes and information contained in multispectral bands 1-7.

<u>Processing Landsat Scenes.</u>

To cover Montana it required about 35 Landsat scenes (a single Landsat scene is roughly 100 miles by 100 miles and has a pixel resolution of about 100 feet by 100 feet—suitable to map individual irrigated fields); on a monthly basis it requires about 175 scenes for the five month irrigation season (May-September). These scenes were selected based on image dates in 2007 between April and the end of September with cloud cover less the 30%.

<u>Landsat processing.</u>
<u>For each scene:</u>

A false color composite image was created in the format of Path_Row_Date (P_R_D) using bands 7_4_3 and projected into Montana State Plane spatial coordinates. A preliminary
transpiration grid was then created by subtracting band 3 from band 4 and eliminating all cell values less than 1 and greater than 200. This grid was named in the format of TPRD. Any values that have values less than 1 are assumed to have no transpiration (plant growth). Values over 200 are generally edge or other anomaly cell values. A preliminary Evaporation grid was then created by taking band 6 and eliminating all cell values less than 100 and greater than 200. This grid was given the name format of EPRD.
These processes were are accomplished in the Arc Info with <u>Taco.aml (see attached aml).</u>

<u>Cloud masking</u>
Clouds have a significant impact on cell values in a Landsat scene and need to be removed before the scene is analyzed. We used USGS EROS Datacenter Landsat products that provide data needed to remove the cloud impacted cells (lndsr.P_R_D). The lndsr data has 16 subdataset that can be used for evaluations of could cover and masking. The subdataset 16 (Fmask) has a compilation of clouds (value 4), shadows (value 2), water (value 1), and other areas (value 0). We combined the value 0 data with the TPRD and EPRD and this will eliminated data that affected by clouds and water and not appropriate for our Landsat-based ET analysis.

<u>Determine hot and cold cell pixel values</u>
Irrigation grid mask-

The Landsat process we developed analyzes the relative 30 meter pixel (90 feet by 90 feet) values in a scene. This process requires selection of which pixels represent the highest water use area (cold pixel) and which pixel values have the least water use areas (hot pixels). This process requires a subjective interpretation by a skilled agricultural engineer with intuitive understanding of the area and how water is being used. This is a time consuming process and subject to inconsistencies. The process was automated to select cold and hot pixel values for land determined to be irrigated. To do this a an irrigation grid mask was developed for each Landsat scene. This grid is developed by clipping the existing irrigation shape file (SWP_irr_bg_5.shp) with the outline of the scene boundary and converted to a grid with unique ids with a naming format of Path_Row_Clip_Irrigaton (PRCI).

PRTD cold pixel value-
The TPRD grid with was then combined with the PRCI grid to have a masked grid that includes only those areas that are irrigated and have no cloud cover. The cold pixel value is determined by selecting the highest 1% of cell values and assigning the lowest cell value of that subset as the cold pixel value (CPV). For the TPRD grid the hot pixel value is 1. The field Trf was then added (Transpiration reference) to the TPRD grid and the cell valued was calculated as:
Trf (4,2) = TPRD cell value / CPV

EPRD hot and cold pixel values-
The EPRD grid was then combined with PRCI grid to find the highest and lowest 1% of the cell values and set the cold pixel value (CPV) as the highest cell value of the lowest 1% and the hot pixel value (HPV) as the lowest cell value of the highest 1%. Then a field Erf (Evaporation reference) was added to the EPRD grid and the cell value calculated as:
Erf (4,2)= (HPV- EPRD cell value) / (HPV-CPV).

With this calculation there were values that are less than 0 (those values that are higher than the lowest values of the 1% of the selected set). These values were then set to 0. The E and the T grids were then combined to create a a grid with ET values. The E and T grids now have fields (Trf and Erf) decimal values that vary from 0.00 to values greater the 1.15. The values greater than 1.15 are mostly edge anomalies or cloud edges and are not used in this evaluation. Now the E and T grids for reference E (Erf) and reference T (Trf) values less than 1.15 were selected and a new grid calculated ETPRD :
ETPRD = (Erf +Trf)*50 as an integer.

This gives a ETPRD grid with an integer cell value and a cell count. When this is done for all the Landsat scenes we have ETrf grids that estimate reference water use for each Landsat scene, with the cloud and water surfaces removed and can now be related to available weather station data to determine estimated water use. At this point one can take any land cover polygons and evaluate their water use for each available Landsat scene and extrapolate those values to seasonal water use.

<u>Irrigation ETrf evaluation by Landsat scene.</u>

In this process the irrigated land in a Landsat Path_Row with the ETPRD grids for that location. Then the cell values are summarized for each irrigated field IDs and the average ETrf is calculated for each of the irrigated fields. First combine the irrigation clip grid (MPR) for the Path Row in the “Irr grid” directory for each of the Landsat ETPRD s. This combined grid will have cell attributes for each of the unique irrigated field IDs of “Count” and “ETPRD”.
Add a field “ET” (8,0) and calc = Count * ETPRD and save
Then summarize on MPR (unique irrigated field id)
    Sum Count and sum ET add new field “ETrf” (5,1) and calc
ETrf= Sum_ET / sum_Count and save
The ETrf is the average reference ET value for each unique field id for that PRD Landsat scene.
This summary table is then joined to the irrigation polygon shape file for that P_R (PRim) and add new fields are added to that shapefile:
    CPR (6,0) = Sum_Count
    ETPR (5,1) = ETrf

This process is then repeated for each of the dated Landsat scenes in that Path_Row.

- Irrigation Water Diversion and Consumption

Consumptive use for each individual parcel was derived via the Landsat-ET estimation procedure (described previously).

Field application was based on the method of irrigation (if available – FLU data only) and the county in which each parcel was located. If the method of irrigation was identified as pivot, then an application efficiency of 80% was assumed. If the method of irrigation was otherwise identified (sprinkler, flood) or not indicated at all (WRS data), then the field application was calculated using on-farm efficiencies from the Water Conservation and Salvage Report for Montana (SCS, 1978). In cases where a county was represent in more than one basin (Deer Lodge, Lewis & Clark, Silver Bow, Fallon, Wibaux), the highest efficiency reported was used.

Once the individual field applications were determined, the fields were aggregated by county and assigned to source (groundwater or surface water) based on the percentages identified in the USGS 2000 Water Use document.

Diversion/withdrawals were calculated based on the source of the water supply (groundwater, surface water) and the county in which each parcel was located. If the source was groundwater, conveyance efficiency was assumed to be 100%. If the source was surface water, then the amount of water withdrawn was calculated using conveyance efficiencies from the Water Conservation and Salvage Report for Montana (SCS, 1978). In cases where a county was represent in more than one basin (Deer Lodge, Lewis & Clark, Silver Bow, Fallon, Wibaux), the highest efficiency reported was used.

After the consumptive use, field application, and amounts withdrawn were calculated; each parcel was assigned to 8 digit HUCs based on location. This assumes that the source HUC and place of use HUC are identical, which may not necessarily be the case. In a few cases (Upper Missouri Basin), where irrigation projects transferred water to acres outside of the source basin, HUC's were reassigned.

- Public (Community) Water Supplies

Public water supplies (PWS) were identified via two sources: 1) Montana Public Water System Sources database (MT- DEQ, accessed through the Montana GIS portal – data published 9/19/2012); and 2) the EPA Safe Drinking Water Information System (SDWIS). For each source, all active systems classified as community systems, or consecutive connections to community systems were initially selected. Non-Transient, Non-Community (NTNC) and Transient, Non-Community (TNC) were not included.

These two data sources result in an overlapping dataset for state regulated systems along with a unique dataset of tribal PWS from SDWIS. The state regulated systems were combined by applying the following rules:

When available, use the DEQ population numbers rather than SDWIS.
Remove systems in the DEQ data if identified as "Closed" in SDWIS.
Remove systems in the DEQ data if classified as NTNC or TNC in SDWIS.

Remove systems from DEQ or SDWIS if source of water was identified as “Purchased”
Remove systems in the DEQ data if readily identified as water bottling/condition firms not already removed under 4)
Remove DEQ systems not identified in SDWIS if there are no resident users.
Include SDWIS systems not listed in the DEQ database.

HUCs and counties for SDWIS systems not found in the DEQ database were assigned by searching/cross-referencing:

DEQ Montana Drinking Water Watch Database – for primary source of consecutive connections
DNRC Water Rights Query System
MBMG GWIC database
Tribal websites
Topographic maps

DEQ resident users for three systems (resorts) were revised based on information from the DEQ Montana Drinking Water Watch Database. These systems were identified by preliminary comparison of county PWS residents with countywide population estimates. In the case of two counties (Silver Bow and Gallatin), initial estimates of PWS resident users exceeded the county-wide population.

PWS users for cities and towns (as designated by the 2010 Census) were adjusted to populations reported in the 2010 census.

Water withdrawn by each PWS was estimated using values of per capita day use reported by county in the USGS 2010 document applied to the number of resident users. An additional 10 gallons per day was applied to non-resident users of the PWS.

Consumptive Use by PWS was assumed to be 37% of withdrawals (DNRC, 1975; USGS, 1986), consistent with USGS 2010 document. One exception to this is the City of Butte, which withdraws water from the Big Hole (HUC 10020004) for use in the Upper Clark Fork (17010201). In this case, all water withdrawn from the Big Hole is assumed to be consumed.

(Note: The 37% consumptive use percentage appears to have originated from the results of a questionnaire sent to public water supplies. The resulting statistics indicated that of the water withdrawn, 62% was used by residential users (who consumed 50%) and 38% was used by industrial users (who consumed 15% - per USGS unpublished data). The resulting overall consumption percentage (.62)(.5)+(.38)(.15) = .367 or 36.7%.)

- Domestic (Self-Supplied)

The number of self-supplied domestic users was calculated by subtracting PWS resident users spatially located within each HUC from 2010 population estimates (also by HUC). The number of PWS resident users spatially located within each HUC may differ than PWS resident users served by the source HUC.

The amount of water withdrawn by domestic users was assumed to be 78 gpd per person (DNRC, 1986; DNRC, 1975) - consistent with the 2010 USGS documentation. Per the 1986 document, this estimate of water use was derived from statistics of municipal systems serving less than 55 users.

Consumptive Use by PWS was assumed to be 50% of withdrawals. This is consistent with the 50% residential use assumed in PWS estimates (mostly consisting of lawn irrigation), and is comparable to recent estimates of consumptive use provided by the DNRC to WPIC.

All domestic water use was assumed to groundwater – differs from USGS procedure (95% statewide).

- Stock

The number of livestock (Cows, Sheep, Hogs) was taken from NASS data for 2010 - consistent with the 2010 USGS documentation.

Water withdrawn was estimated using the assumptions applied in the USGS 2010 report:

Beef Cattle:	15 gpd/head
Dairy Cattle:	23 gpd/head
Hogs and Pigs:	5 gpd/head
Sheep:	2 gpd/head

All water withdrawn was assumed to be consumed.

Assignment of source was based on county percentages of groundwater and surface water originally assigned in the 1986 DNRC document. These percentages originated from water rights permits issued at the time of that report.

Assignment to HUC was performed by assuming uniform distribution of stock - consistent with the 2010 USGS documentation.

- Self-Supplied Industrial

Duplication of the USGS procedure for industrial users in 2010 was not possible. Instead, past USGS estimates (1985 through 2000 - where both HUC and county estimates were provided, and 2005 which provided only usage by county) were analyzed to determine HUC assignment of those counties where the majority of the water use occurred. Then, applying these HUC assignments to the 2005 USGS data updated estimates were provided (representing 90% of the statewide industrial water use). All other industrial use estimates remain as reported in the 2000 water use document.

- Thermoelectric

Thermoelectric users were identified from Energy Information Administration reporting (EIA923 – Power Plant Operations Report, Schedule 8D: Cooling System information). Six projects were identified in the report, three of which reported withdrawals and consumptive use for cooling:

Colstrip (Rosebud County)
J E Corette Plant (Yellowstone County)
Hardin Generator Project (Big Horn County)

There are additional thermoelectric projects in the state (EIA –Electricity Data Browser, accessed 9/12) that did not appear in the EIA 923 Report. There are also projects listed in the water rights database for power generation (likely as a complimentary use, but not necessarily) that are not found in the EIA data.

However, the list above is comparable to previous reports (DNRC, USGS) – with some allowance for new plant construction and variation in annual generation needs.

With regard to consumptive use, the Corette plant reported only a small percentage of withdrawals as consumed. Both the Hardin Generator Project and Colstrip reported consumptive use equivalent to withdrawals.

Assignment of generators to HUC was performed through cross-referencing EIA data, the DNRC Water Rights Information System, and topographic maps.

- Hydropower

Hydropower projects were primarily identified from the EIA – Electricity Data Browser (User Generated Report: List of Plants for All Fuels, Montana, All Sectors, accessed 9/12). The recently restarted Flint Creek project was not included in the EIA data and was identified by the basin hydrologist. Projects were then sorted into three categories:

Federal facilities where electricity is generated but is generally not the primary purpose of the project (Canyon Ferry, Fort Peck, Yellowtail, Libby, Hungry Horse)
Facilities where the primary purpose is electricity generation (PPL, Avista, and PacifiCorp)
Facilities where electricity is generated but may not the primary purpose of the project (Broadwater, Tiber, Turnbull Hydro projects, South Dry Creek Hydro, Flint Creek).

Plant capacity and 2010 Net Generation was taken from the EIA (Except for Fort Peck – USACE data, and Ryan Dam – which upgraded to 60 MW in 2013).

Turbine capacity was taken from water rights filings associated with generation – since water rights were typically filed at turbine capacity. *It should be noted that most projects have additional flow rights above and beyond turbine capacity in order to fill and store water behind the dams.*

- 2010 Water Use was determined by one of three methods:

1. If a gage was located immediately downstream of a project, with no significant tributary flows between the dam and the gage, then daily flows were used to estimate water use – subject to the maximum flow capacity of the project.

2. In the case of Fort Peck, this was reported by the USACE.

3. In all other cases, the 2010 water use was estimate by applying a ratio of generation to water use – derived from the generation and turbine capacity of the project. These ratios were constructed in units of KW/cfs in order to compare them with previous "turbine factors" employed by the DNRC in the Missouri River Model and cited later in the Smith River EA Addendum (the ratios are comparable).

Assignment of generators to HUC was performed through cross-referencing EIA data, the DNRC Water Rights Information System, and topographic maps.

- Notes:

1. There are additional hydropower projects planned or in development based on water right permit applications. These projects do not involve new reservoir construction, but rather use existing projects already in use for other purposes (irrigation). Such projects have been applied for and permitted by Gibson Dam Hydroelectric Co. LLC, Clark Canyon Hydro LLC, and Diamond T Bar Ranch Inc (for a second generating unit off the South Dry Creek Hydro project canal).

2. Hydropower facilities are normally considered non-consumptive. However, many of these projects are associated with large reservoirs from which water evaporates. Additionally, at smaller scales, some of these projects may divert water from one watershed for use in another (South Dry Creek Hydro) – in which case they would be considered 100% consumptive.

3. The estimates of water use in 2010 may be misleading since the use of water by hydroelectric facilities is more accurately represented by the water rights – turbine capacity for the projects and evaluated on a basis of flows. In most cases, these projects have a right to use all of the water from a source, with flows in excess of capacity (and thus potentially available for additional appropriation) occurring only for a few weeks or months of the year.

4. In the case of USACE projects, the issue of water rights and water use is more complicated.