October 13, 2010
Revised Feb 2, 2012

Water Year 2010 Discharge Estimates at Kajakai Dam, Afghanistan

1.0 Introduction

Kajakai Dam is located on the Helmand River in southern Afghanistan (32.323N, 65.119E). The dam is an earth and rockfill embankment type dam 90 m high with a crest 10 m wide and 270 m long. The dam was completed in 1953 with an uncontrolled, 113 m wide primary spillway cut into the adjacent bedrock. Excavation on the emergency spillway was left incomplete in 1979. The powerhouse was completed in 1975 with two 16.5 MW generating units (#1 & #3) and an open center bay for an additional unit (#2). Kajakai is the primary source of power for the Kandahar City region and supplies water to the heavily irrigated Helmand Valley. A June 2010 satellite image of the dam is provided in Figure 1.

Daily reports of discharge estimates from Kajakai Dam and this annual water budget report were prepared at the request of the U.S. Marine Corps. The U.S. Army Corps of Engineers Reachback Operations Center (UROC) facilitated the request. The purpose of this report was to estimate the amount of water discharged from Kajakai dam during Water Year 2010 (October 1, 2009 to September 30, 2010) and compare to previous years. No streamflow gages are currently operational at the dam or on the Helmand River. The only method to estimate flows on the Helmand River is to use Kajakai Dam as a control structure and calculate flows leaving the dam. It was not possible to calculate reservoir inflows because of the lack of accurate reservoir stage-storage curves.

2.0 Methods

There are three outlets for water to exit Kajakai reservoir. Water is able to pass through the powerhouse unit penstocks, the irrigation jet valves and over the primary spillway. As part of the USAID funded Afghanistan Infrastructure and Rehabilitation Program, daily reports are provided by personnel at Kajakai Dam. The reports include measured water levels at the irrigation tower, percent jet valve openings and powerhouse units on-line. Spreadsheets were developed to calculate daily average flow from the powerhouse units, jet valves and spillway based on available head in the reservoir. *(turbine discharge revised with updated performance curves)*

All elevations used in this report are based on the irrigation tower benchmark of 1050.15 m. This benchmark is a local construction datum. Compared to the 5 m IfSAR digital elevation model (WGS84/EGM96), the construction datum is approximately 15 m higher. Reservoir levels are measured once daily at approximately 0900 local time by dropping a tape down from the irrigation tower benchmark. Water levels are also measured at the bridge 1 km downstream of the dam, the bridge elevation is unknown. The powerhouse pressure gage was not used because of inconsistencies and the whole meter increments of measurements.

Depending on the available head, each powerhouse unit has a discharge capacity between 23 and 32.5 m^3/s. The discharge rating curve for the units was obtained from the 2004 Voith-Siemens turbine performance curves and is summarized in Figure 2.

Three 84 inch (213 cm) hollow jet valves are located west of the powerhouse. The valves are used to meet downstream irrigation demands. Depending on head, each jet valve has a capacity of 58 to 77 m^3/s when open 100%. Each jet valve can be regulated to open a defined percentage with normal operations between 20% and 70% open. All valves are typically closed in late December and January for downstream irrigation canal maintenance. The discharge rating curve for a single jet valve is provided in Figure 3 and was obtained from the 1971 International Engineering Company report “Kajakai Spillway Gate Study”.

When the reservoir level reaches an elevation of 1033.5 m, water begins to overflow the primary spillway and discharge back into the Helmand River via a 1,500 m by-pass channel. Flow over the spillway was estimated using the broad-crested weir equation with a spillway width of 113 m, see Figure 4. Flow calculations over the spillway are an approximation given the debris and uneven spillway configuration. WY2009 discharge estimates were updated using the 1033.5 m spillway elevation with a reduction in annual discharge volumes.

3.0 Results

From October 1, 2009 to September 30, 2010 total discharge from Kajakai Dam into the Helmand River was 5,922 M-m^3 (million cubic meters). Annual discharge volumes for the spillway, jet valves and powerhouse are provided in Table 1. Discharge from the powerhouse was greater in 2010 than 2009 because Unit #3 was off-line for most of 2009 for rehabilitation. Table 2 includes monthly discharge volumes at the Helmand River gage below Kajakai Dam for water years 1948 to 1979, note dam regulation began January 28, 1953 and the powerhouse was completed 1975. The amount of water released from Kajakai during WY2010 was below the 1953 to 1980 average of 6,021 M-m^3. The Excel spreadsheet "Kajakai Dam Discharge and Elevation WY2010 Revised 2Feb2012" contains reported daily values from the dam and the calculated discharge rates and volumes.

Figure 5 is a graph of daily reservoir level (blue line) and total discharge (red line) from the dam. The spillway crest and the 1999 to 2009 average reservoir level are provided for reference and illustrate the drought conditions of 1999 to 2004 when reservoir levels rarely reached the spillway crest.

A graph of daily discharge from the jet valves, spillway and the powerhouse units is provided in Figure 6. Discharge from the powerhouse turbines provide a base flow between 50 to 60 m^3/s year-round into the Helmand River. The large spikes in flow from February to June are discharge from the uncontrolled spillway. Total discharge peaked at 927.4 m^3/s on May 7, 2010. A comparison of historic discharge from Kajakai to WY2010 is provided in Figure 7. The highest recorded flow (1953 to 1980) downstream of Kajakai was 1,760 m^3/s on April 29, 1967. The February 1991 flood is reported to be the flood of record but no gages were active.

The noteworthy event of WY2010 was the early cresting of the spillway. Between February 6th and 9th the reservoir level increased 3.3 m with the spillway cresting on the 9th. Historic records indicate the spillway typically crest in April, see Table 3. One cause of the early filling was the above average temperatures in early February and precipitation in the form of rainfall in the lower elevations of the dam's watershed (Robert Blevins, personal comm.). The warming trend also melted snow and decreased the snow water equivalent of the watershed's snowpack by 1 billion cubic meters between January 31st and February 14th (ERDC/CRREL Afghanistan Snowpack Assessment Feb 18, 2010) creating early runoff. Kajakai also started the winter with a higher reservoir level in 2010 as compared to 2009. Lost reservoir storage volume since 1953 due to sedimentation may also be contributing to earlier spilling at Kajakai, see Figure 8.

Another significant event was the rapid increase in discharge from Kajakai on May 7, 2010. Discharge into the Helmand increased from 414 to 927 m^3/s within a 48 hour period. This increase was a combination of additional jet valve openings and a rainfall event in the upper Helmand watershed on May 4th. On August 9th there was a 0.9 m increase in the reservoir level associated with monsoon rainfall in the eastern half of the upper Helmand watershed. Runoff from this event was contained within the reservoir with no large increase in discharge.

Recommendations include installing water level gages on the irrigation tower and bridge downstream of Kajakai Dam. Survey of the benchmarks at Kajakai with survey grade GPS equipment is recommended to relate the local construction datum to a known vertical datum. A new rating curve survey of the Helmand River at the bridge is also recommended. LIDAR survey of the reservoir up to Deh Rawod during low water levels is recommended for updating the stage-storage curve of the reservoir and estimating sedimentation rates.

Acknowledgements
The assistance of Sayed Rasul Baqi, Bruce Marler and Michael Swart at Kajakai Dam is greatly appreciated.

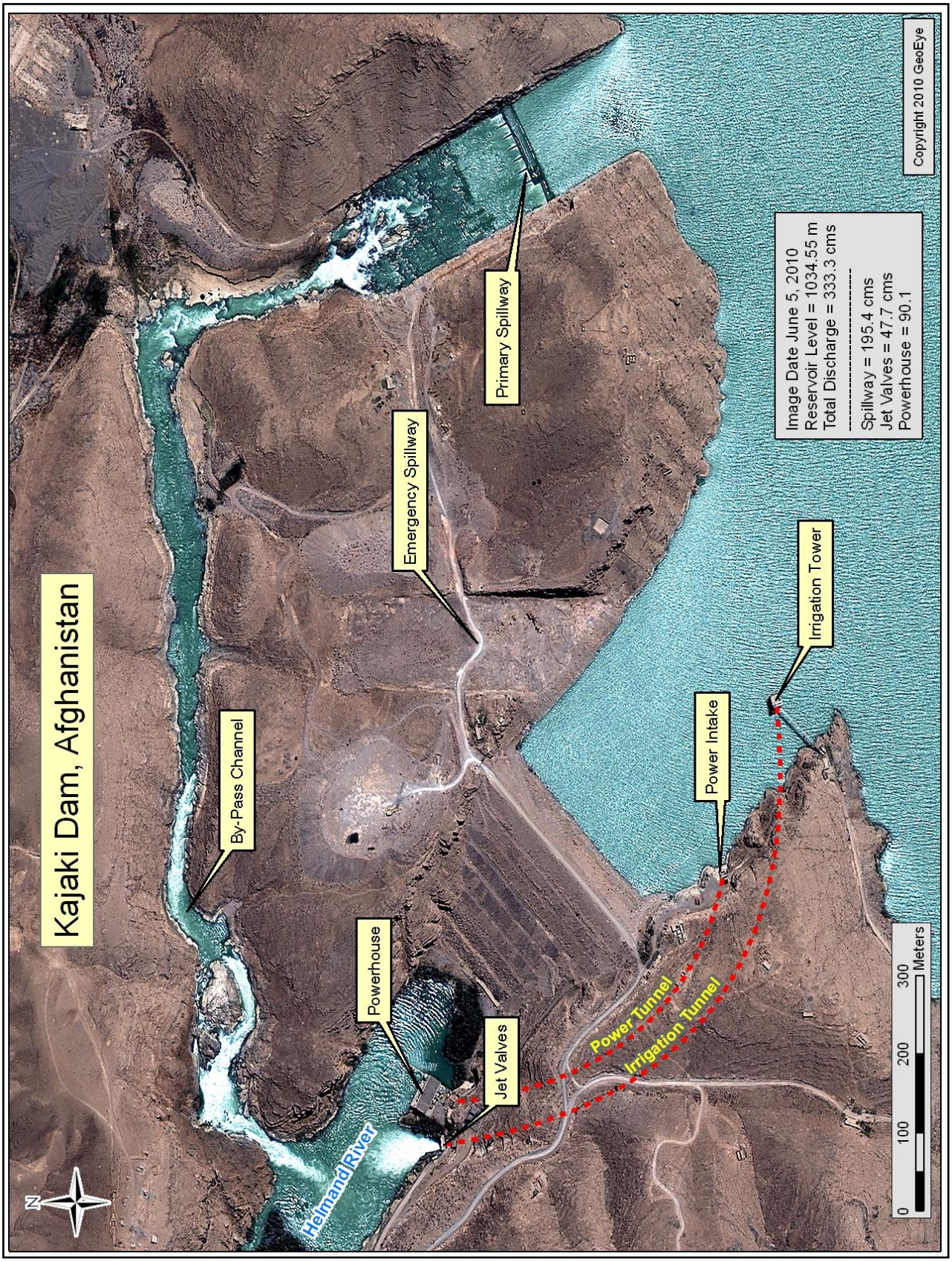

Figure 1 – Kajakai Dam Layout

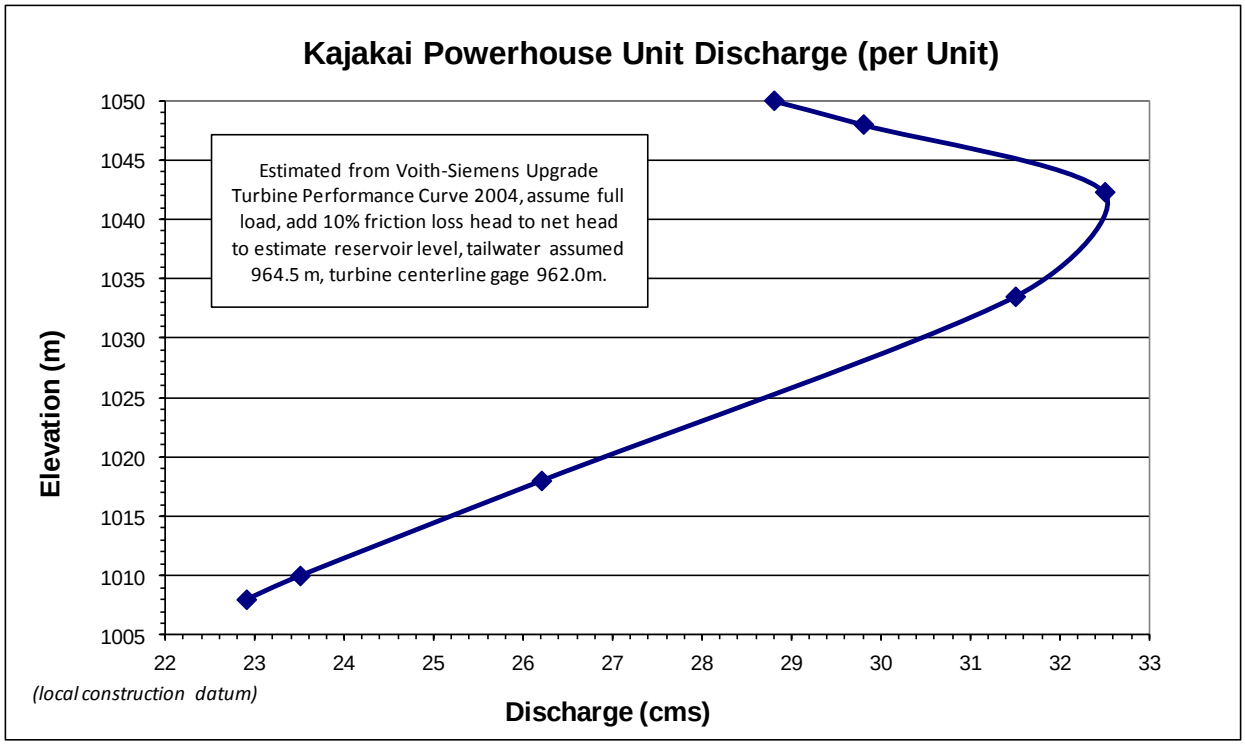

Figure 2 – Estimated Discharge Capacity of Kajakai Generating Unit *(updated 2Feb2012)*

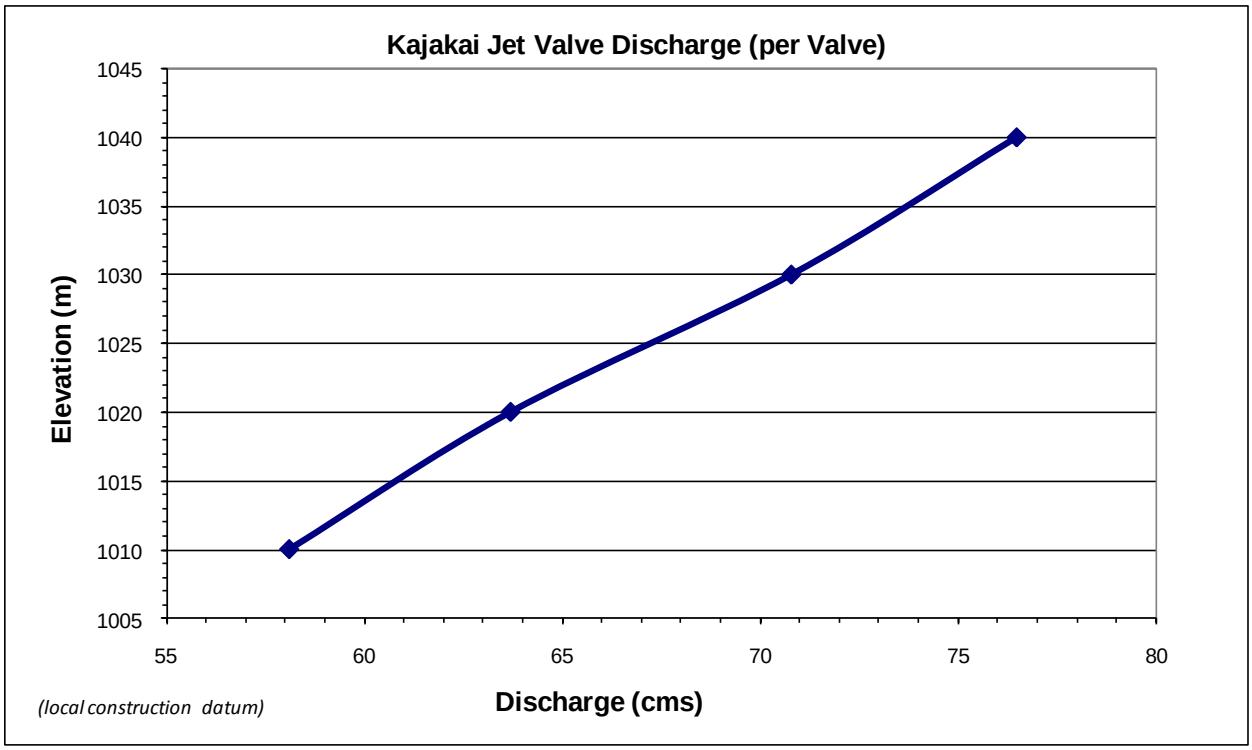

Figure 3 – Estimated Discharge Capacity of 84 inch Jet Valve

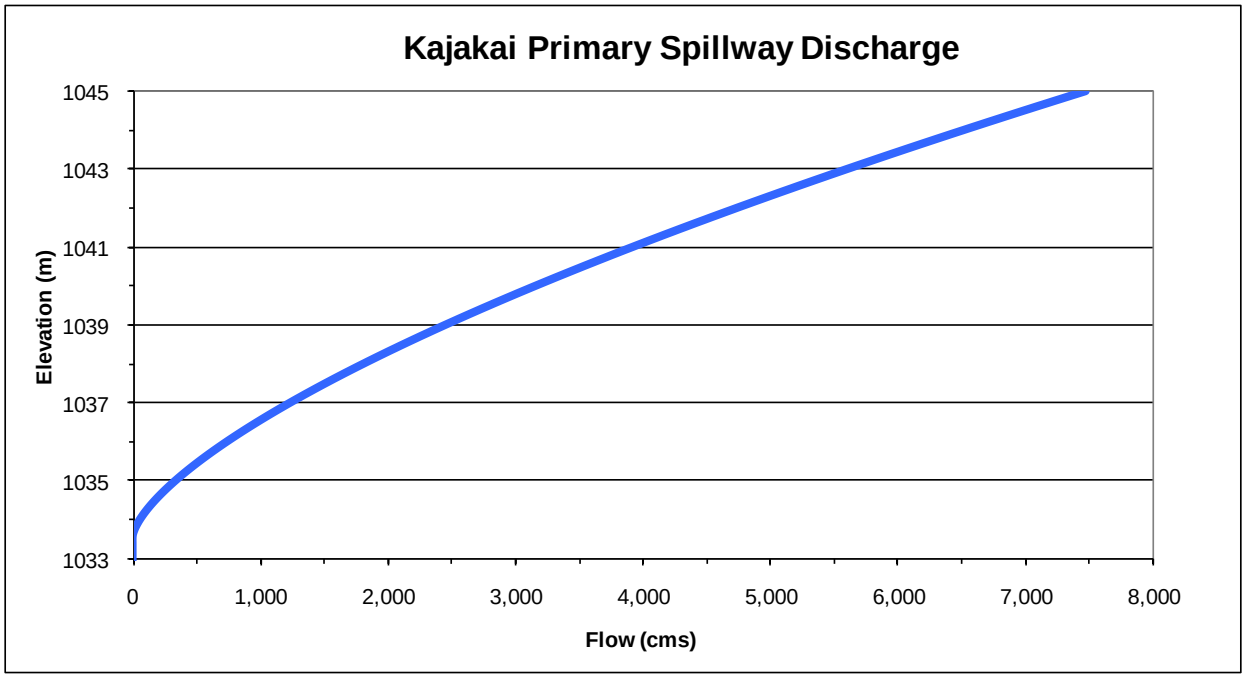

Figure 4 – Estimated Discharge Capacity Primary Spillway (invert 1033.5 m, 113 m wide, weir coeff 1.704)

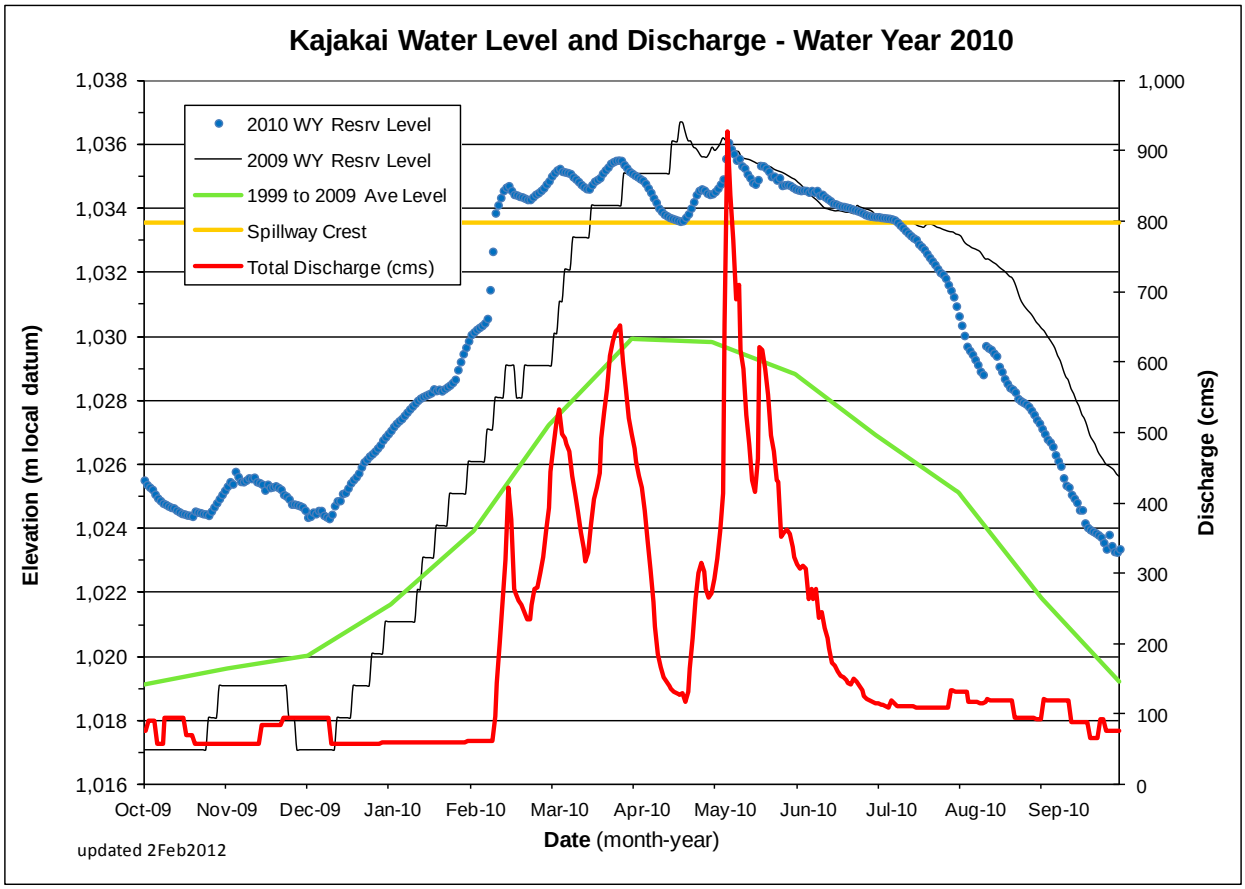

Figure 5 – Reservoir Level and Total Discharge from Kajakai Dam Water Year 2010

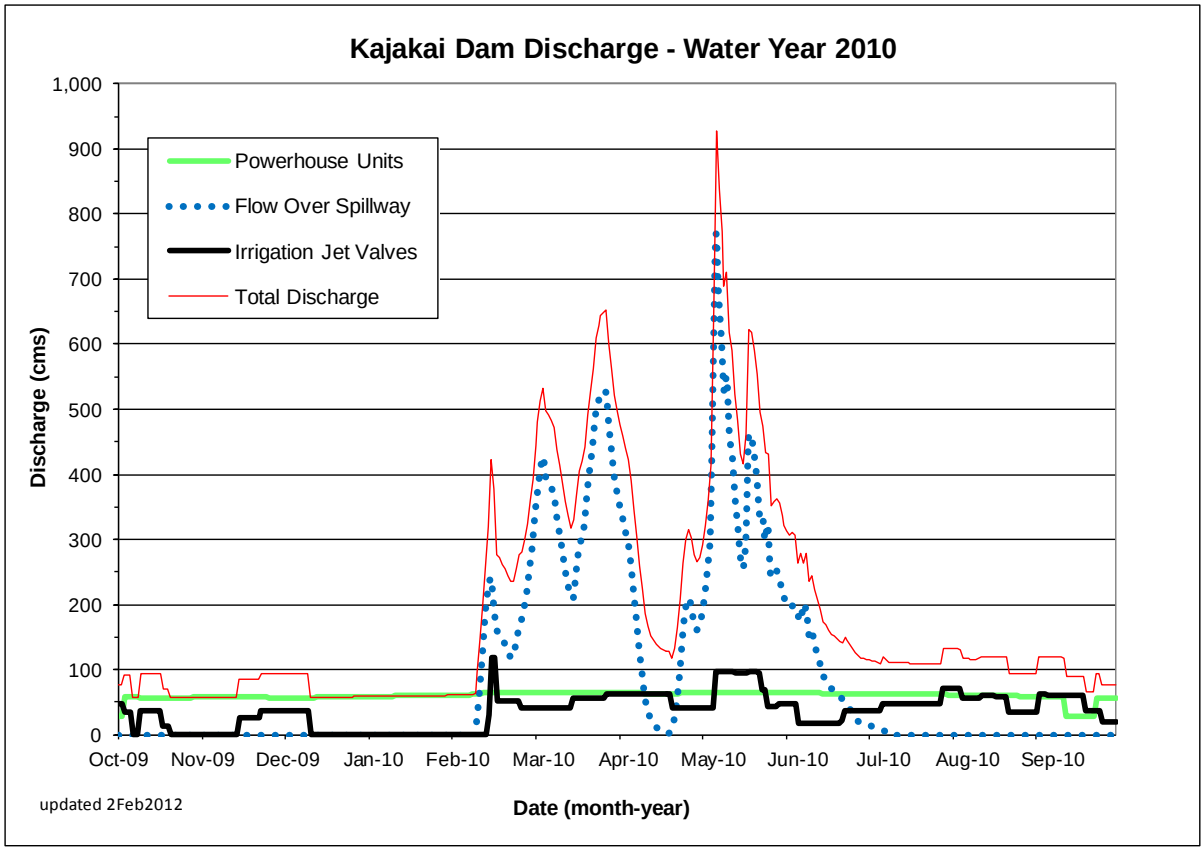

Figure 6 – Discharge from Kajakai Dam Water Year 2010

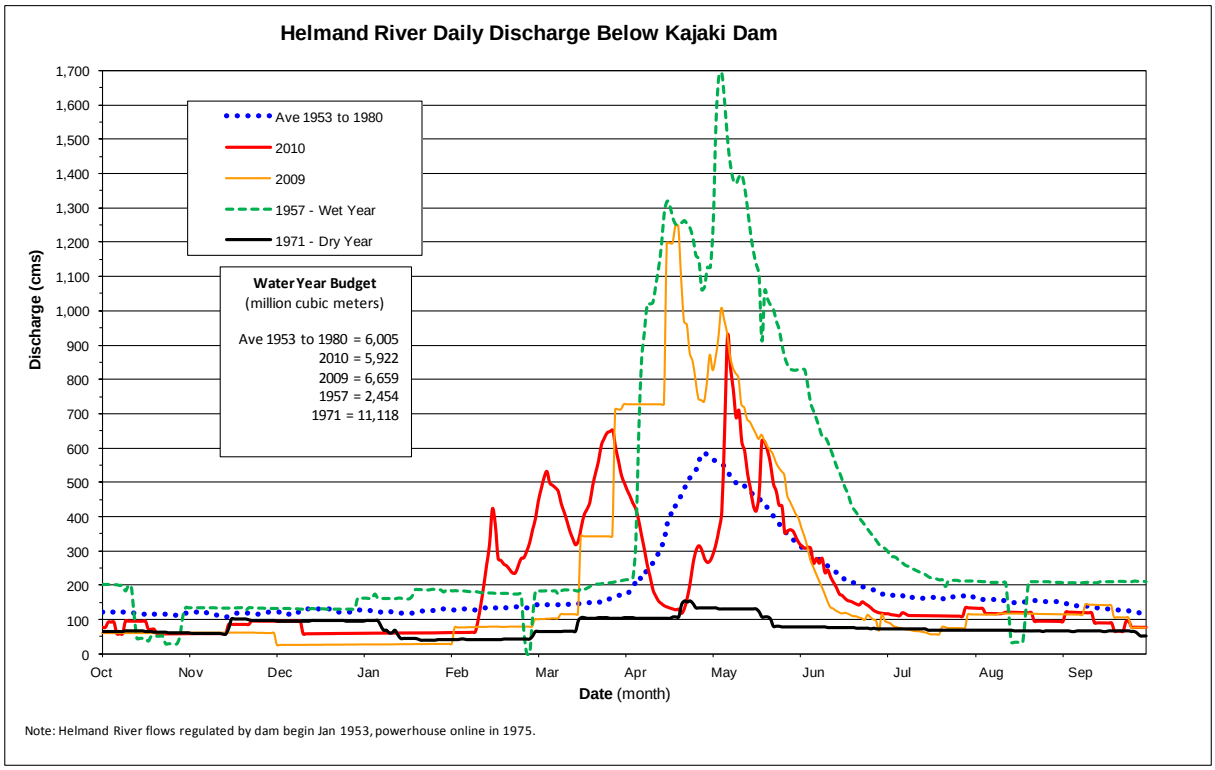

Figure 7 – Comparison of Water Year 2010 Discharge from Kajakai Dam

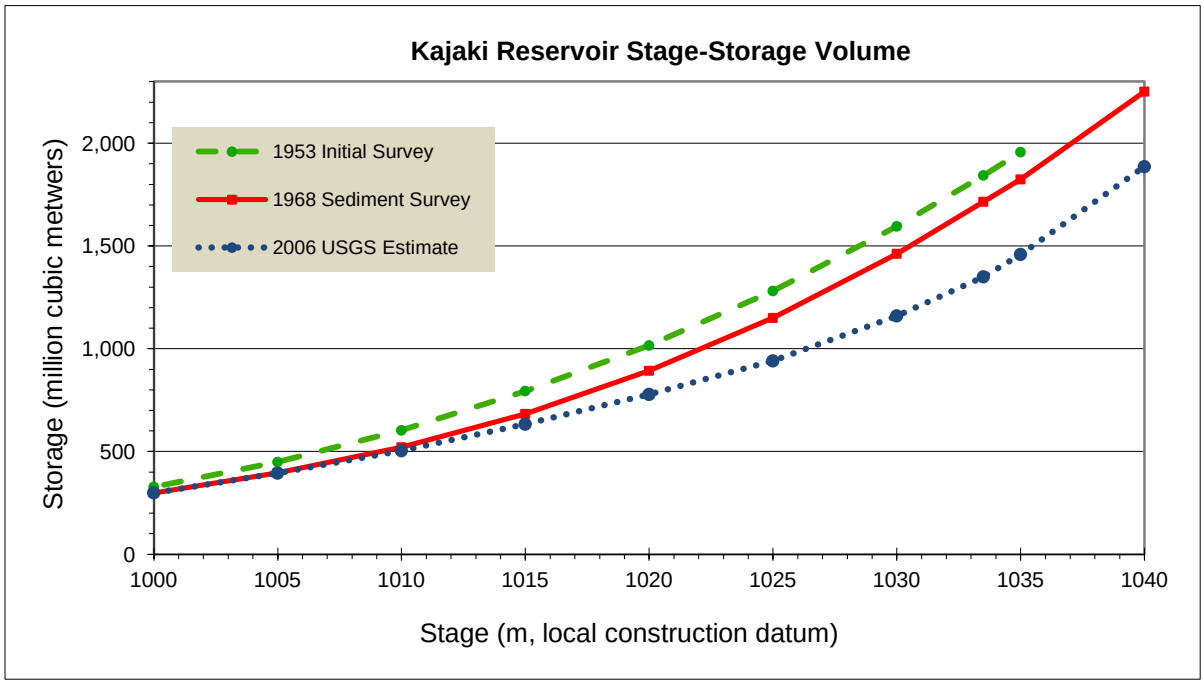

Figure 8 – Stage-Storage Volumes for Kajakai Reservoir

Figure 8 Stage-Storage Sources:

1953 and 1968:
Perkins, D.C., and J.K. Culbertson. 1970. Hydrographic and Sedimentation Survey of Kajakai Reservoir, Afghanistan. Geological Survey Water – Supply Paper 1608-M, U.S. Geological Survey.

2006:
Vining, K.C., and A.V. Vecchia. 2007. Water Balance Simulations of Runoff and Reservoir Storage for the Upper Helmand Watershed and Kajakai Reservoir, Central Afghanistan. Scientific Investigations Report 2007-5148, U.S. Geological Survey.

Table 1 – 2010 and Historic Average Water Year Discharge Volumes from Kajakai Dam (million cubic meters)

Year	Total Discharge	Powerhouse Units	Irrigation Jet Valves	Flow over Spillway
Ave 1953 to 1980	6,005	---	---	---
2009	6,659	967	1,477	4,215
2010	5,922	1,890	1,132	2,901

Table 2 – Helmand River below Kajakai Dam Discharge in million cubic meters (M-m^3)

Source: Data 1948 to 1980 U.S. Geological Survey, http://waterdata.usgs.gov/nwis

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1948	110	140	165	161	175	740	1,566	1,016	334	166	104	110	4,787
1949	149	177	192	193	276	882	2,258	1,260	461	240	167	149	6,404
1950	193	217	231	275	279	596	1,264	2,101	749	277	155	147	6,484
1951	187	198	203	211	219	830	1,649	2,464	940	352	190	170	7,613
1952	194	221	233	243	358	927	1,687	1,134	429	216	143	154	5,941
1953	198	217	224	217	172	382	510	579	562	525	518	349	4,453
1954	301	242	186	226	419	477	1,087	1,721	672	325	408	336	6,399
1955	303	303	366	503	433	362	401	523	464	336	380	350	4,724
1956	344	333	351	332	299	386	2,366	1,336	381	479	576	465	7,647
1957	289	345	358	463	384	516	2,554	3,173	1,389	636	470	542	11,118
1958	554	263	497	552	492	567	1,032	1,069	630	589	577	524	7,348
1959	502	355	316	316	284	379	961	1,006	606	574	540	424	6,262
1960	325	272	415	341	254	287	259	1,086	686	343	332	312	4,911
1961	311	534	529	495	402	285	471	1,674	601	354	349	276	6,281
1962	332	376	544	509	419	424	319	423	416	263	186	154	4,365
1963	146	213	223	342	414	433	305	347	452	407	379	291	3,953
1964	197	191	509	470	388	459	785	1,317	603	573	516	233	6,239
1965	284	276	276	354	457	543	1,662	2,672	1,200	614	336	318	8,993
1966	353	567	560	522	439	468	469	423	302	309	302	264	4,978
1967	266	294	291	207	198	234	1,056	2,094	852	569	542	305	6,908
1968	272	295	300	463	454	522	672	1,347	772	586	536	349	6,568
1969	287	273	286	299	494	538	1,844	1,667	784	423	375	375	7,645
1970	359	347	356	513	434	471	483	412	293	262	237	197	4,364
1971	172	209	256	151	103	227	301	300	197	189	181	168	2,454
1972	148	173	163	142	130	165	1,252	1,660	795	608	566	504	6,305
1973	466	376	280	270	257	359	577	1,034	523	561	524	456	5,684
1974	412	318	270	202	260	189	302	532	382	413	377	339	3,996
1975	258	235	309	227	256	314	841	1,667	664	442	396	368	5,976
1976	353	299	284	292	218	431	2,272	2,441	869	502	494	459	8,914
1977	465	428	348	199	318	457	662	696	490	403	356	317	5,138
1978	228	186	285	254	195	302	851	838	393	372	367	309	4,581
1979	297	251	252	217	162	301	1,058	1,072	587	383	350	309	5,238
1980	280	255	268	246	279	735	2,079						
Average	***289***	***284***	***313***	***315***	***313***	***460***	***1,087***	***1,284***	***609***	***415***	***373***	***313***	***6,021***
2009	163	160	71	76	190	690	2,211	1,852	436	201	311	298	6,659
2010	194	197	183	160	509	1,293	657	1,361	522	303	300	243	5,922

Table 3 – Duration of Spillway Flow at Kajakai Dam

Year	Water Year Discharge ($M\text{-}m^3$)	Flow Over Spillway From	Flow Over Spillway To	Data Source
1953	4,453	No Spill	No Spill	(a)
1954	6,399	Apr 18	Jun 20	(a)
1955	4,724	May 28	Jul 15	(a)
1956	7,647	Apr 5	Aug 5	(b)
1957	11,118	Apr 5	Jul 18	(b)
1958	7,348	Apr 14	Jun 14	(b)
1959	6,262	Apr 15	Jun 12	(b)
1960	4,911	May 7	Jun 18	(b)
1961	6,281	Apr 27	Jun 19	(b)
1962	4,365	No Spill	No Spill	(b)
1963	3,953	Jun 4	Jun 26	(b)
1964	6,239	Apr 22	Jun 12	(b)
1965	8,993	Apr 12	Jul 11	(b)
1966	4,978	No Spill	No Spill	(b)
1967	6,908	Apr 19	Jul 1	(b)
1968	6,568	Apr 25	Jun 25	(b)
1969	7,645	Apr 3	Jun 28	(b)
1970	4,364	No Spill	No Spill	(b)
1971	2,454	No Spill	No Spill	(b)
1972	6,305	Apr 10	Jun 20	(b)
1973	5,684	Apr 24	Jun 17	(b)
1974	3,996	May 6	May 31	(b)
1975	5,976	Apr 17	Jun 28	(b)
1976	8,914	Apr 14	Jul 3	(b)
1977	5,138	Apr 18	Jun 4	(a)
1978	4,581	Apr 13	Jun 5	(a)
1979	5,238	Apr 11	Jun 16	(a)
1980	---	Mar 23	Jun 25	(a)
	1981 to 1997 Data Not Available			
1998	---	No Spill	No Spill	(c)
1999	---	May	May	(c)
2000	---	No Spill	No Spill	(c)
2001	---	No Spill	No Spill	(c)
2002	---	No Spill	No Spill	(c)
2003	---	Apr	Jul	(c)
2004	---	No Spill	No Spill	(c)
2005	---	Apr	Jul	(c)
2006	---	May	Jun	(c)
2007	---	Mar	Jul	(c)
2008	---	Apr	Jun	(c)
2009	6,659	Mar 10	Jul 26	(d)
2010	5,922	Feb 9	Jul 5	(d)

Sources:
(a) estimated from daily reservoir storage records
(b) "Kajaki Hydroelectric Project Condition Assessment, Dam Safety Assessment Report" Table 2.2, Acres International, Apr 2004.
(c) estimated from powerhouse gage records, insufficient data to define exact day of month, estimates require confirmation
(d) daily updates from dam provided by Afghanistan Infrastructure and Rehabilitation Program