J 5.4 CREATIVE APPLICATIONS OF HYDRO-CLIAMTE PREDICTIONS FOR A DROUGHT MANAGEMENT PLAN

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INTRODUCTION

The Flathead Lake Drought Management Plan (DMP) is being developed for use as a federally mandated input to assist in the operations of the Kerr Hydro-Electric Project (PPL-Montana) and the Hungry Horse Reservoir (Bureau of Reclamation) when conflicts occur between the minimum in-stream flow requirements of Article 56 and the lake levels set forth in Article 43 of the project license. The DMP is implemented by use of hydro-climate based inputs.

The generation of hydro-electric power causes a draw down of water levels in Flathead Lake during the months of October to March. Spring snowmelt runoff and precipitation are counted on to re-fill the lake to levels needed to support the multi-million dollar summer recreation industry on the Lake.

Additionally, the Flathead runoff is used to maintain minimum downstream flow contributions for endangered species in the Columbia River system. Figure 1 shows the location of the Flathead basin in western Montana.

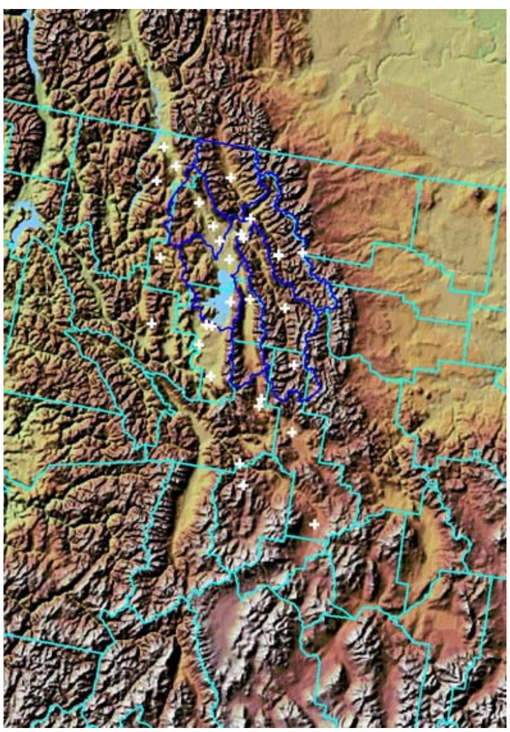

Figure 1 Location of Flathead Lake in Montana. Note the dark blue basin boundary.

The Flathead lake elevation varies from 2,883 ft to 2,893 ft during the course of the water Year. A variation of even a foot or less below the June 1 target elevation of 2,893 ft can have a significant economic impact on Flathead lake recreational businesses.

2. PROGNOSTIC HYDRO-CLIMATE INDICES

The primary goal of the hydro-climate analyses was to develop, if possible, reliable drought management plan triggers. Three triggers were developed: one diagnostic and two prognostic. The two prognostic triggers are:

1. August/September Multi-variate ENSO Index or Aug/Sep MEI and
2. June/November Southern Oscillation Index or June/Nov SOI.

The MEI (Wolter et al, 1993) provides a measure of the sub-tropical energy available and its northward transport from the sub-tropical Pacific Ocean to more temperate latitudes. The MEI relies on the use of six variables: sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C). Positive values of the MEI tend to indicate an El Nino condition exists in the Pacific Ocean while negative values support development of La Nina conditions.

A detailed discussion of the MEI and its climate applications can be found at the following Internet site: http://www.cdc.noaa.gov/people/klaus.wolter/MEI/index.html. The MEI was developed by the NOAA-CIRES Climate Diagnostic Center.

The SOI (Nicholls N. 1988) provides an insight into the climate influences in the western Pacific Ocean. The **Southern Oscillation Index (SOI)** is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin**.** The SOI provides similar insight into El Nino and La Nina conditions though the SOI values are opposite in sign with positive values indicating a La Nina condition and negative values indicating an El Nino condition.

A detailed discussion of the SOI can be found at the following Internet site: http://www.bom.gov.au/climate/current/soi2.shtml. The SOI was developed by the Australian Bureau of Meteorology.

These two indices provide the opportunity for a reliable prognostic DMP trigger during the start of the Water Year (WY). A comparison of MEI and SOI values and Montana Climate Division 1 precipitation (see Figure 2) indicated that El Nino conditions were related to below normal WY precipitation while La Nina patterns favored above normal WY precipitation. Table 2 summarizes the differences found.

Table 2 Montana CD-1 Precipitation comparisons

Weather Pattern	Oct-Dec Normal Precip	Oct-Mar Normal Precip
La Nina Avg	6.82" (+1.49")	12.59" (+2.26")
Normal	5.33"	10.33"
El Nino Avg	4.85" (-0.48")	8.52" (-1.81")
Avg 10 Driest Yr	3.25" (-2.08")	6.21"(-4.12")

Table 3 shows the comparison of the MEI, SOI and CD-1 Precipitation for the 10 driest years. When the Aug/Sept MEI value is greater than 0.50 and the corresponding June/Nov SOI is less than 0.50, a dry water year outlook is issued in December that identifies the need to mandate the DMP in January.

3. DIAGNOSTIC HYDRO-CLIMATE INDEX

The diagnostic trigger is the October-December Montana Climate Division 1(Figure 2) precipitation. The use of the CD-1 precipitation was an attempt to develop a link into the basin runoff that could be both observed and predicted early in the start of the WY.

This DMP diagnostic trigger is available in January in time for the traditional start of the WY runoff forecast period. Whenever the CD-1 October- December precipitation is < 3.50 inches and the MEI index is > 0.50, the recommendation is that the DMP be invoked. Table 3 shows the verification of these two hydro-climate indices and the Flathead Lake basin's driest years. Use of the MEI and SOI prognostic indices provides a 75 per cent correct WY forecast.

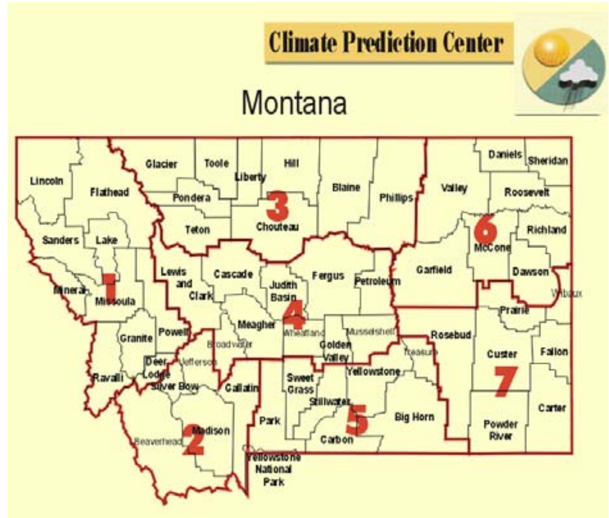

Figure 2 Montana Climate Divisions

HDR recommended the following rules be considered as the preliminary DMP triggers:

1. **Outlook trigger (October-December release):** When the Aug/Sep MEI value is greater than 0.50 and the corresponding SOI is less than 0.50, that a dry WY outlook be issued for the October to March period. It identifies a potential need to invoke the DMP in January.

2. **Critical trigger (January release):** When the Oct-Dec Montana Climate Division 1 precipitation is less than 3.50 inches, a **critically dry Water Year** (Oct-Mar precipitation < 70% of normal) is expected and the DMP be invoked in January.

Table 3 Comparison of the ten driest Oct-Mar and Oct-Dec precipitation periods (Inches) and MEI (Multi-Variant ENSO Index) and SOI (Southern Oscillation Index)

Driest 0ct-Mar	0ct-Mar	Oct-Dec	Aug/Sep MEI	Jun/Nov SOI		Driest Oct-Dec	Oct-Dec	Oct-Mar	Percent Normal	Aug/Sep MEI	Jun/No SOI
1977	5.35	**2.29**	**1.02**	**-0.52**		**1977**	**2.29**	5.35	52%	**1.0**	**-0.52**
1944	5.82	**3.49**	E0.0	0.22		**1945**	**2.57**	6.50	63%	**E0.54**	**-0.52**
1994	5.83	**3.19**	**1.0**	**-1.1**		**1988**	**2.60**	6.16	60%	**1.9**	**-1.35**
2001	5.95	**3.12**	-0.24	0.57		**1955**	**3.02**	7.07	68%	-1.8	0.18
1988	6.16	**2.60**	**1.9**	**-1.35**		**2001**	**3.12**	5.95	58%	-0.24	+0.57
1941	6.40	4.27	**E2.1**	**-1.8**		**1994**	**3.19**	5.83	56%	**1.0**	**-1.1**
1945	6.50	**2.57**	**E0.54**	**-0.52**		**1926**	**3.38**	7.45	**72%**		
1905	6.63	**3.38**	?	**?**		**1905**	**3.38**	6.63	64%		
1937	6.77	**3.04**	?	-0.42		**1929**	**3.41**	7.65	**74%**		
1973	6.93	4.52	**1.6**	**-1.28**		**1944**	**3.49**	5.82	56%	E0.0	0.22
Trigger		**<3.50**	**>+0.5**	**<-0.5**			**<3.50**	6.44	62%	**+0.50**	**-0.50**

4. FLATHEAD PRECIPITATION/RUNOFF INDEX (FPRI)

These preliminary drought triggers were refined and the forecast system enhanced during the alternatives development of Phase 2. The first refinement of the forecast triggers involved refining the precipitation index used. Figure 1 showed the Montana Climate Division 1 region location of the stations used for the January DMP precipitation trigger. The alternatives development of Phase 2 resulted in the refinement of the precipitation index to eight key precipitation stations located in the key sub-basins of the Flathead basin. Figure 3 shows the location of these eight stations.

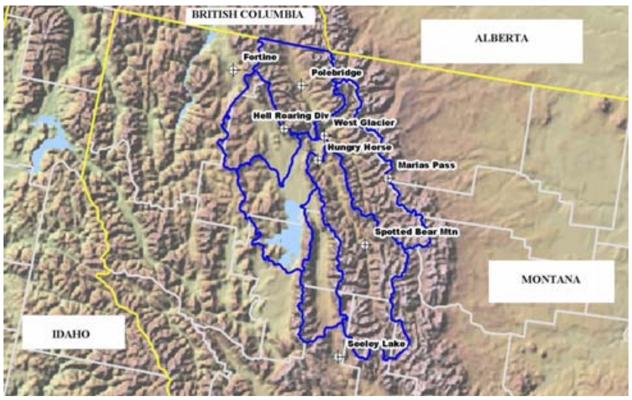

Figure 3 Locations of the key eight precipitation gages used to develop the Flathead Precipitation/Runoff Index (FPRI).

The CD-1 precipitation index was refined by the Flathead Precipitation Runoff Index (FPRI) based on the statistical relationship between the observed April to September runoff and the observed October to April precipitation at eight precipitation stations in the watershed.

The combination of these two indices results in a **greater than 75 percent correct forecast** of a low runoff year from October to December based solely on the MEI value being greater than 0.50, indicating an El Niño climate factor. The application of the precipitation-based FPRI trigger in January, in concert with the MEI, results in an 86 percent correct forecast in January that improves to 96 percent correct in April.

The utilization of Montana Climate Division 1 (MT CD-1) precipitation data in earlier phases of the project was deemed adequate in assessing the basin-wide snow-pack that accrues during the October-March period. The preliminary correlation between these variables and the ensuing spring-summer runoff was deemed to be necessary but not sufficient in performing the preliminary hydro-climatic index evaluations used in the results in Phase 1A.

Table 3 Key eight precipitation stations used to develop the Flathead Precipitation/Runoff Index (FPRI).

North Fork	Station	Elevation (ft)
	West Glacier	3150
	Polebridge	3520
	Fortine 1N	3000
	Hell Roaring Divide	5700

S.-Middle Fork + Swan	Station	Elevation
	West Glacier	3150
	Hungry Horse	3160
	Seeley Lake	4100
	Marias Pass	5250
	Spotted Bear Mtn.	7000

Since the MT CD 1 covers and area much larger than the basins impacting runoff into Flathead Lake, a refined set of precipitation stations with direct contributions to Flathead Lake was tested for predictive relevance. As a result, a 'Flathead Precipitation-Runoff Index' (FPRI) was derived to reduce the uncertainty of the precipitation-runoff relationship and help provide a more robust guideline in monitoring the precipitation of the winter/early spring.

The R^2 of the October-March MT D1 precipitation to the following April-September naturalized runoff is calculated to be approximately 0.71 for the period 1950-2003. By comparison, the R^2 of the FPRI (given information available in early April) is approximately 0.83 when compared to the April-September runoff for the same period.

The FPRI is a combination of sites measuring precipitation in either liquid equivalent (LE) at cooperative observing sites or the snow water equivalent (SWE) at select snow course sites. One set of stations focuses on the status for the combined runoff of the South and Middle Forks of the Flathead River, along with the Swan River (SMS).

The second set of stations is focused on gauging the status and potential runoff of the North Fork of the Flathead River (NF). The result of the FRPI computation is measured in units of thousand acre-feet (KAF). The computed values should be considered a status of the hydro-meteorological condition of the basin at a specific point in time rather than an explicit runoff forecast.

The development of the Flathead Precipitation Runoff Index (FPRI) relies on the statistical relationship of the observed April to September runoff to the October to April precipitation at the key eight precipitation sites. Figure 3 shows the strong relationship of the FPRI forecasted runoff to the observed naturalized runoff.

The MEI is used to anticipate the potential of a low runoff year from October to December. In December the FPRI is added into the forecast equation to determine if the DMP is invoked. The combination of the two indices results in a **greater than 75 percent correct forecast** of a low runoff year from October to December based solely on the MEI value being greater than 0.50 indicating an El Nino climate factor.

In January the application of the precipitation-based FPRI trigger in concert with the MEI results in an 86 percent correct forecast in January that improves to 96 percent correct in April. A key factor in these forecasts is that **no low runoff years** are missed by the forecast scheme.

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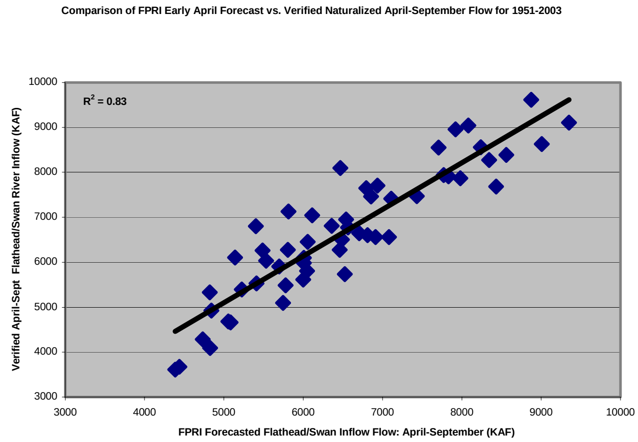

Figure 3 Relationship of the Flathead Precipitation /Runoff Index Forecasted vs. Observed April-September naturalized Runoff

The scheme of the drought triggers does over-predict the occurrence of low runoff years but provides monthly opportunities to revoke the DMP once it has been invoked. Figure 4 shows the verification of the DMP triggers for the period of 1950 –2003 Water Years.

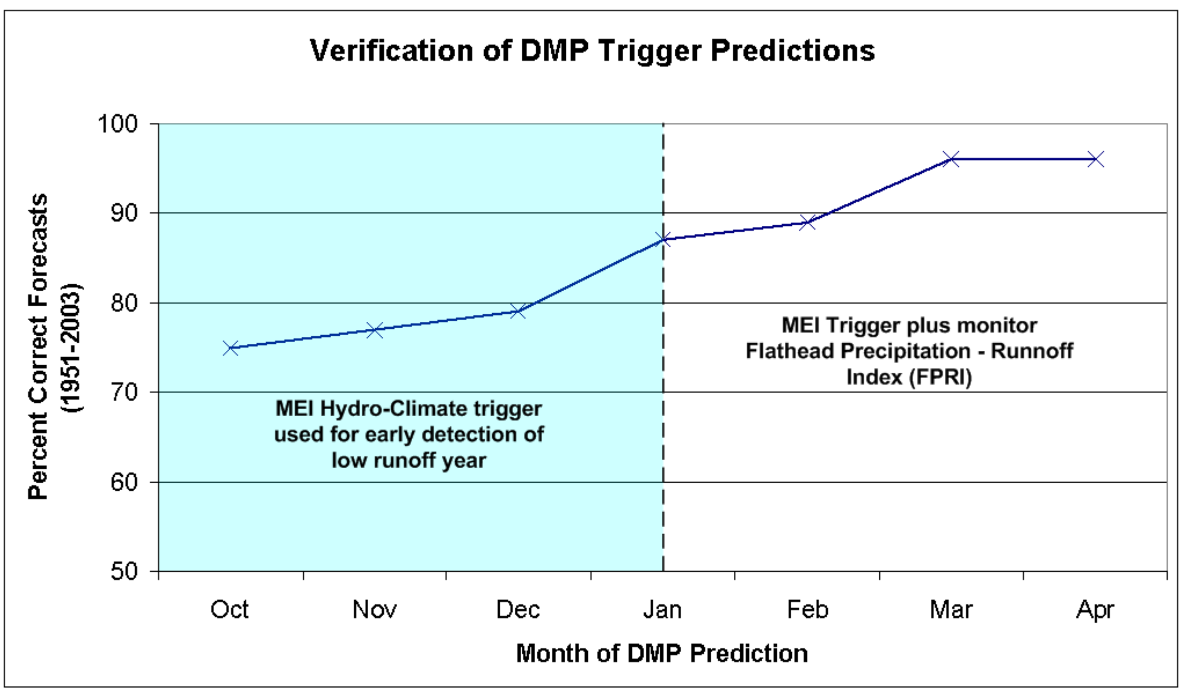

Figure 4 Verification of the DMP triggers for the 1950 –2003 Water Years.

Figure 5 is a flow chart showing the use of the MEI and FPRI drought triggers on a monthly basis from the start of the Water Year in October through the beginning of the spring runoff in April. The use of the "DMP trigger recipe" should result in a reliable set of outlooks and forecasts of both low runoff years and preliminary prediction of the forecast runoff volume.

The technique described was used to produce WY forecasts in December 2002 and 2003. In both cases the WY prediction was accurate. In 2003 the forecast called for 83 percent of normal runoff despite some federal agency forecasts of less than 70 percent of normal runoff. The observed WY runoff was 84 percent. This early series of successes has lead to additional work that will focus on "shaping" the runoff hydro-graph and insuring that flood years are captured by the process as well as the dry years.

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Additional insights were developed with Robert Beduhn, HDR EIS Project Manager and Ms. Allison MacKwen of HDR.

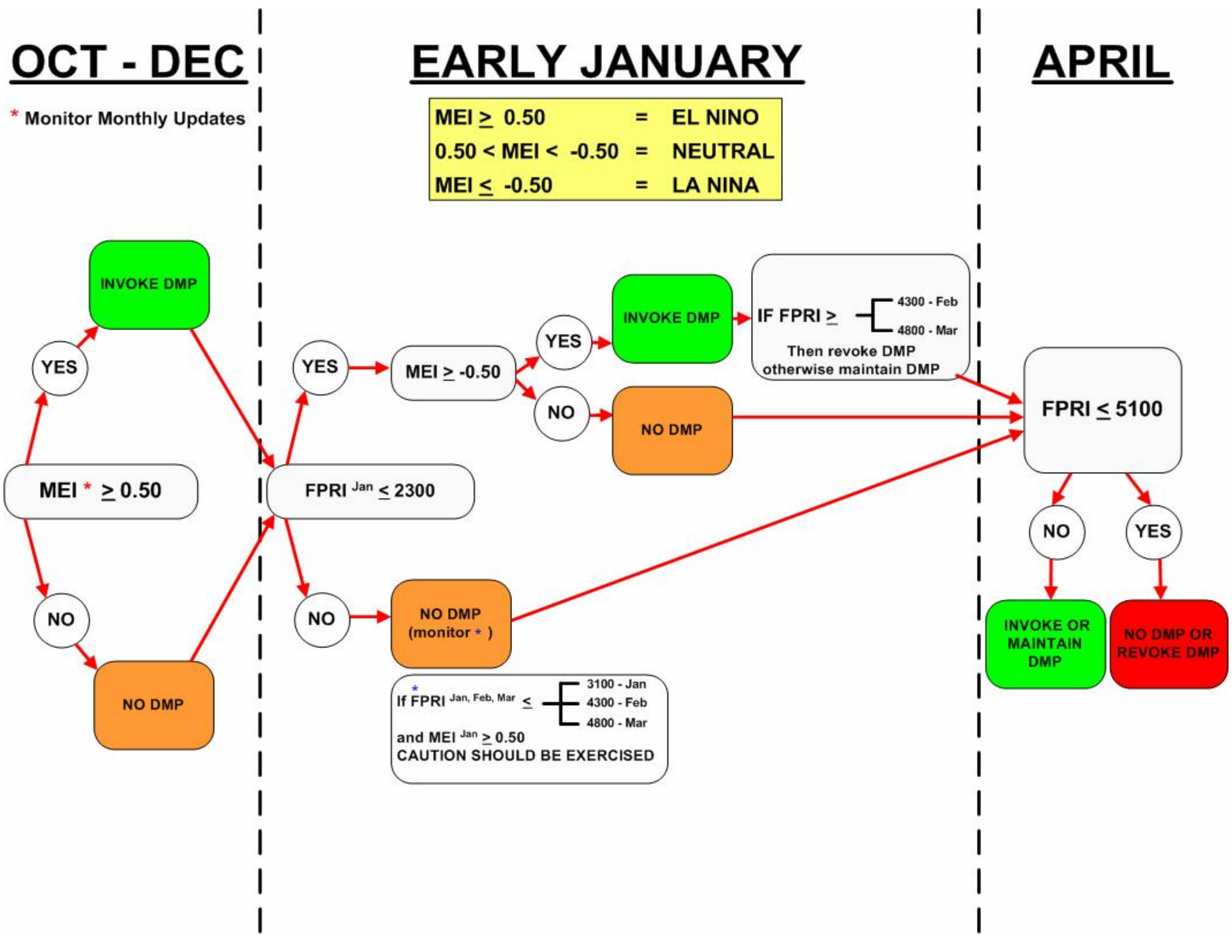

Figure 5 Flathead Lake Drought Management Plan Drought Trigger Flow Chart

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