

2015 Montana Water Supply Initiative
Yellowstone River Basin

Yellowstone Water Budget

(Hydrology and Water Management Overview)

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Helena Montana



Yellowstone Water Budget

Hydrology

- Hydrologic Cycle
- Geography and Basin Characteristics
- Historic Streamflow and Variability

Water Management

- Dams, Reservoirs and Storage
- Concept of Water Budget / Water Balance



Hydrologic Cycle

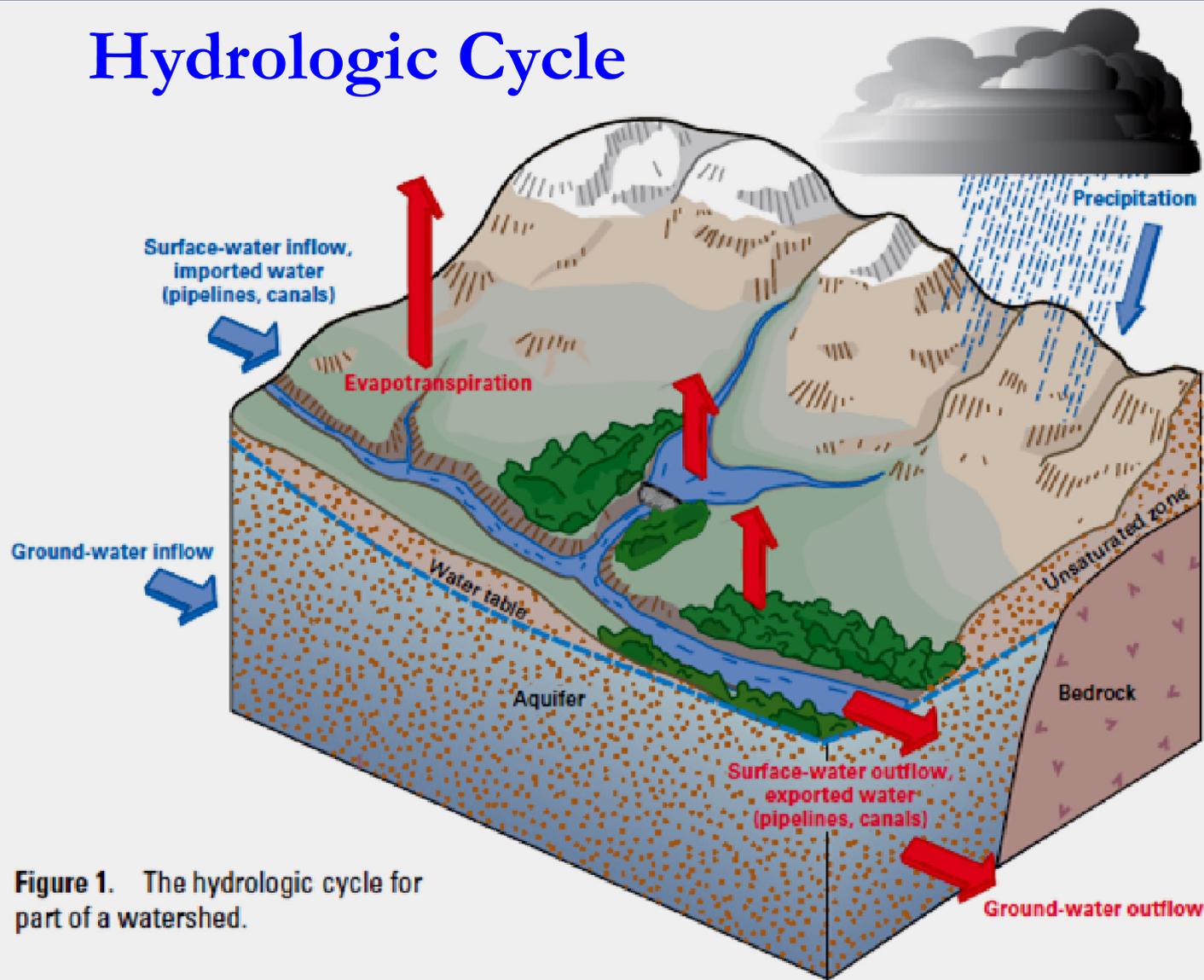


Figure 1. The hydrologic cycle for part of a watershed.

Concept of Water Budget

$$\begin{aligned} & \left(\text{Water In} - \text{Water Out} \right) = \text{Water Balance} \\ & \underbrace{\left(\text{Precip} + \text{Inflow} \right)}_{\text{Water In}} - \underbrace{\left(\text{Cons. Use} + \text{Outflow} \right)}_{\text{Water Out}} = \text{Change in Storage} \end{aligned}$$

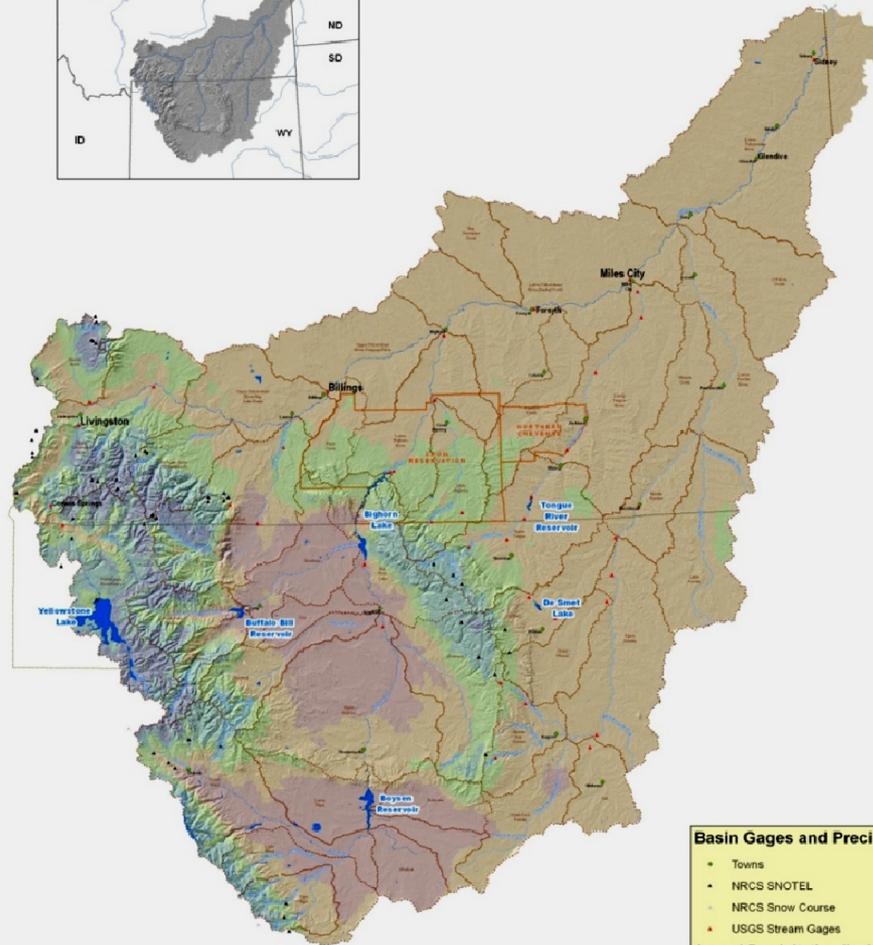
Because water can be stored as groundwater and in surface reservoirs, the Water Balance represents the change in stored water over time (daily, monthly, annual).



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Yellowstone River Basin

Hydrologic Monitoring System



Basin Gages and Precipitation

- Towns
- NRCS SNOTEL
- NRCS Snow Course
- USGS Stream Gages

Annual Precipitation (inches)

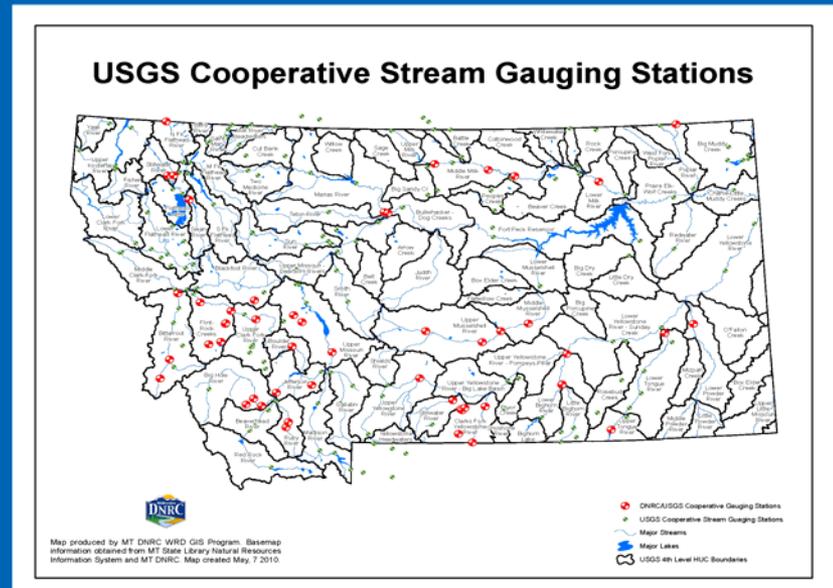
- 5 - 11
- 11 - 17
- 17 - 24
- 24 - 35
- 35 - 69

0 10 20 Miles



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Quantify Montana's Water Supply

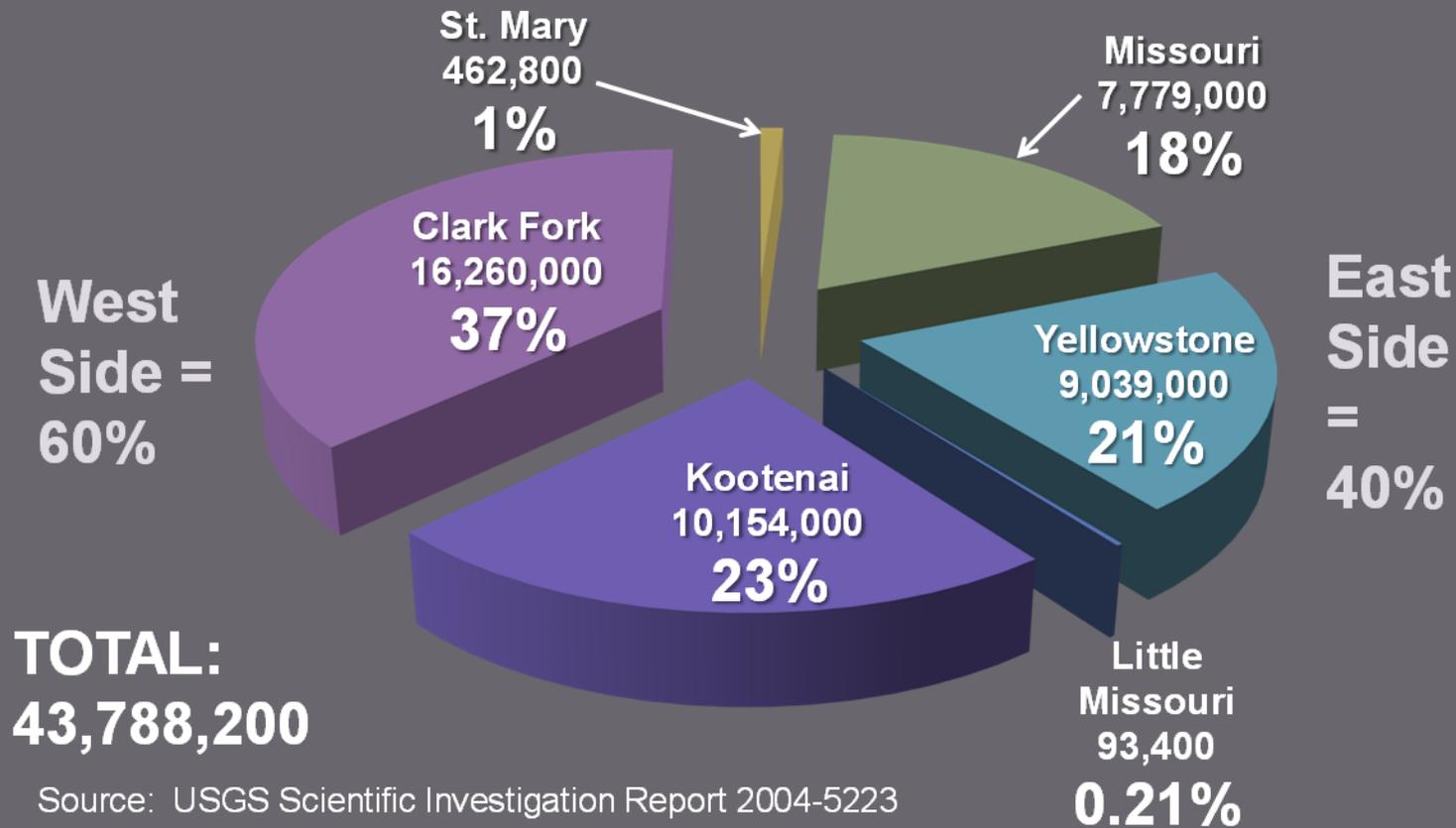


- **218 Gauges Statewide**
- **43 DNRC cost-shares w/ Cooperators (USGS)**
- **\$286,000**
- **62% of WMB's 2012 budget**



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Water in Montana's Rivers
1971-2000 Average Annual Runoff
(ac-ft)

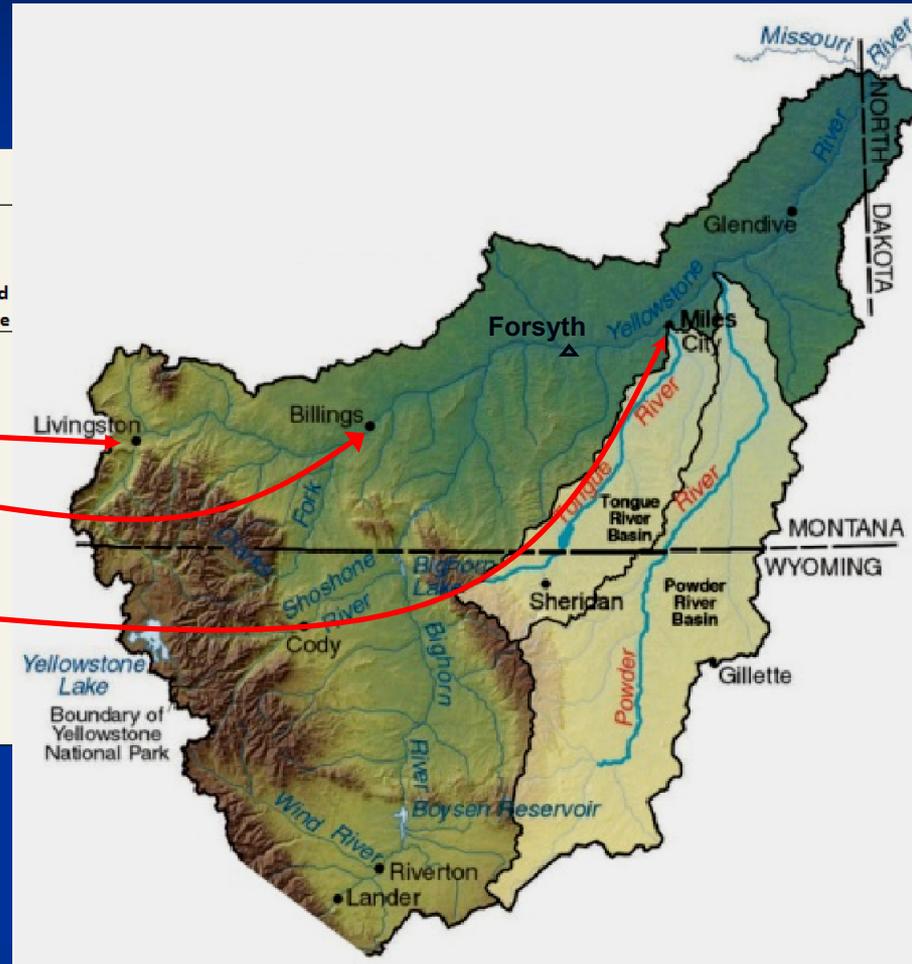


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Geography and Basin Characteristics

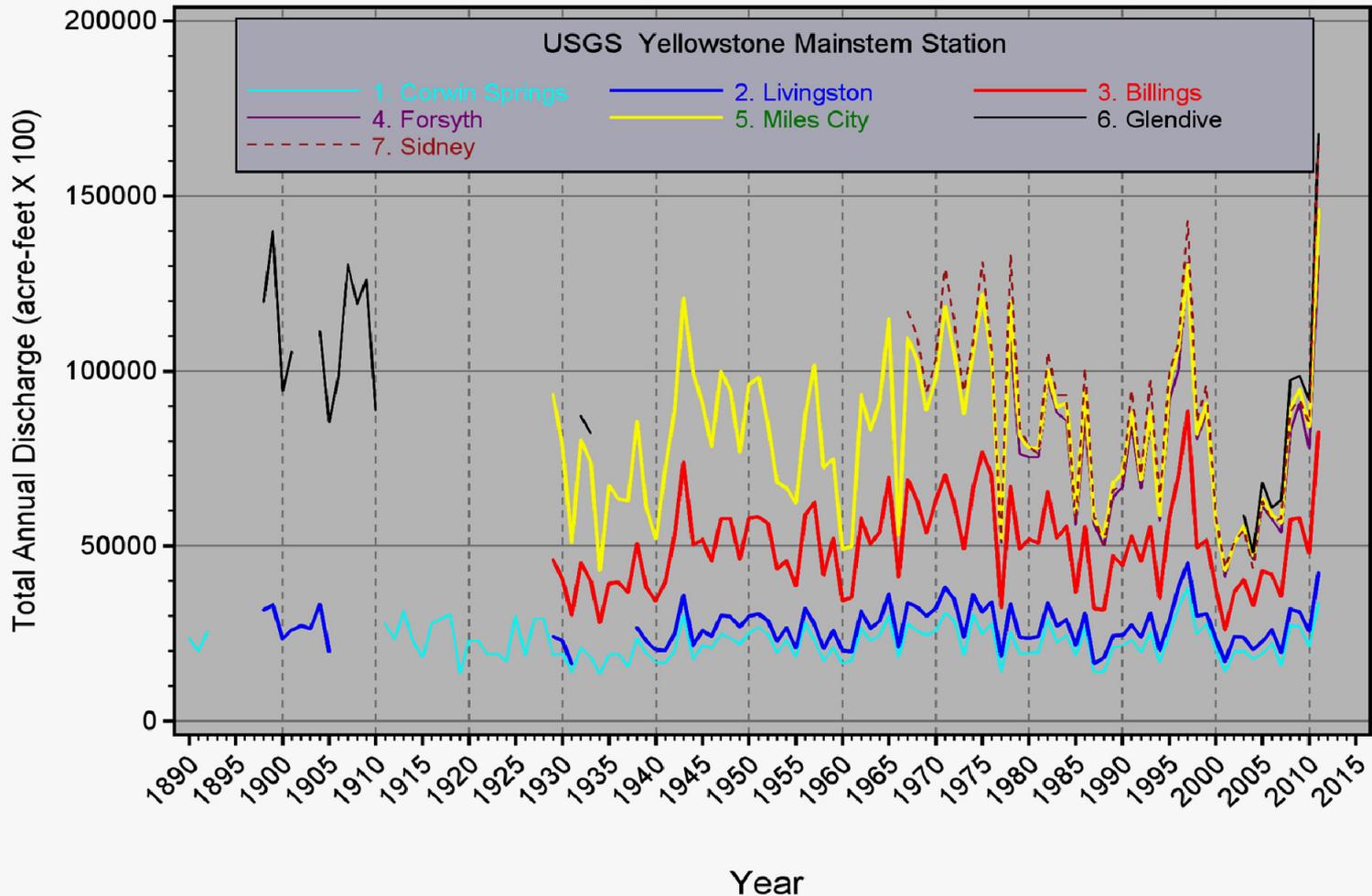
Yellowstone River Basin Drainage Areas

| LOCATION | USGS Station ID | Basin Area (mi ²) | Percent of Total | Period of record of Annual, Monthly, and Mean-Daily Discharge |
|-------------------------------------|-----------------|-------------------------------|------------------|---|
| Yellowstone River at Corwin Springs | 6191500 | 2,619 | 4 | 1930-2011 |
| Yellowstone River near Livingston | 6192500 | 3,551 | 5 | 1930-2011 |
| Yellowstone River at Billings | 6214500 | 11,805 | 17 | 1930-2011 |
| Yellowstone River at Forsyth | 6295000 | 40,146 | 58 | 1977-2011 |
| Yellowstone River at Miles City | 6309000 | 48,253 | 70 | 1930-2011 |
| Yellowstone River at Glendive | 6327500 | 66,788 | 97 | 1930-2011 |
| Yellowstone River near Sidney | 6329500 | 69,083 | 100 | 1930-2011 |



Historic Streamflow and Variability

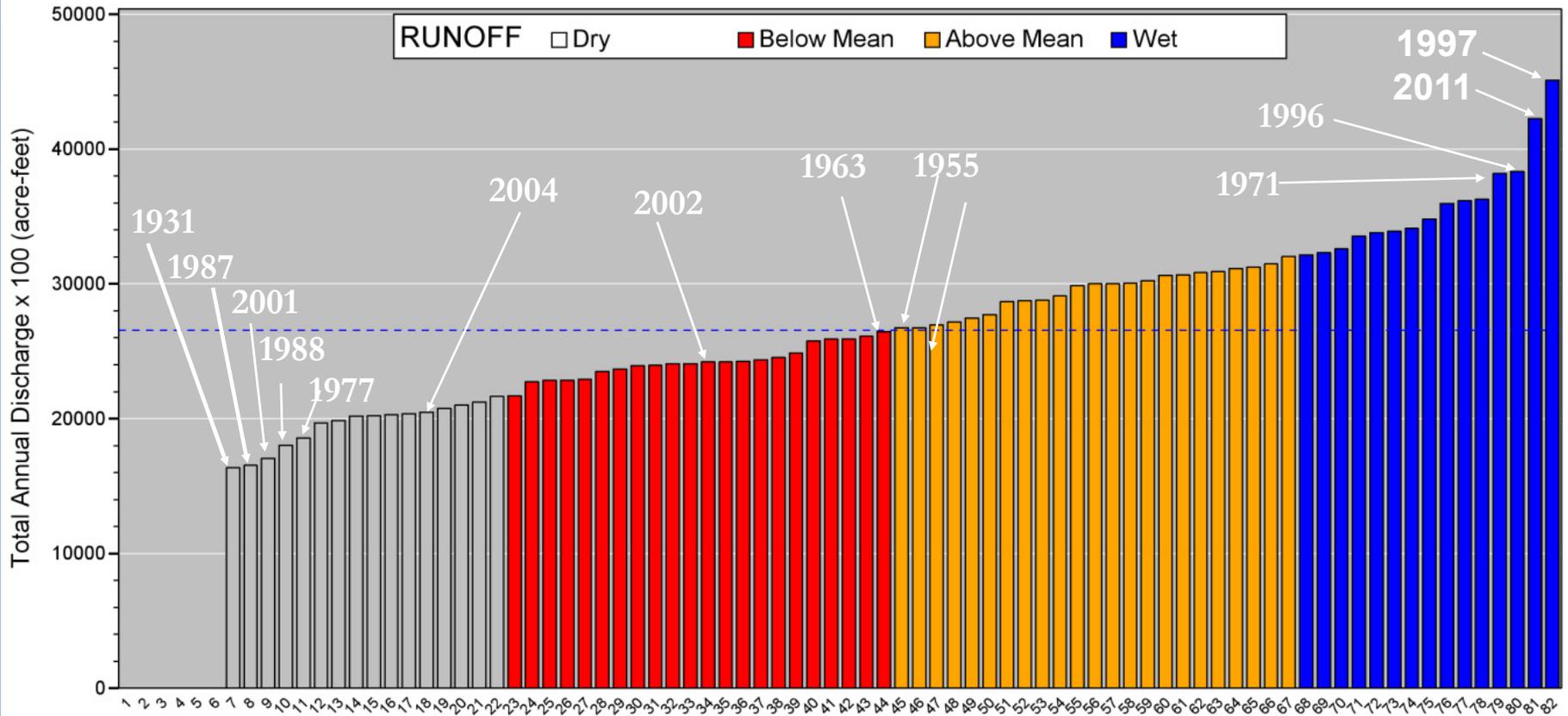
Total Annual Discharge Volume: Yellowstone River Mainstem (Acre-Feet X 100)



(DNRC Water Resources Division March 2013: Total annual calendar-year data retrieved from the U.S. Geological Survey, National Water Information System (NWIS) database.)

Ranking of Annual Discharge Volume From Smallest to Largest

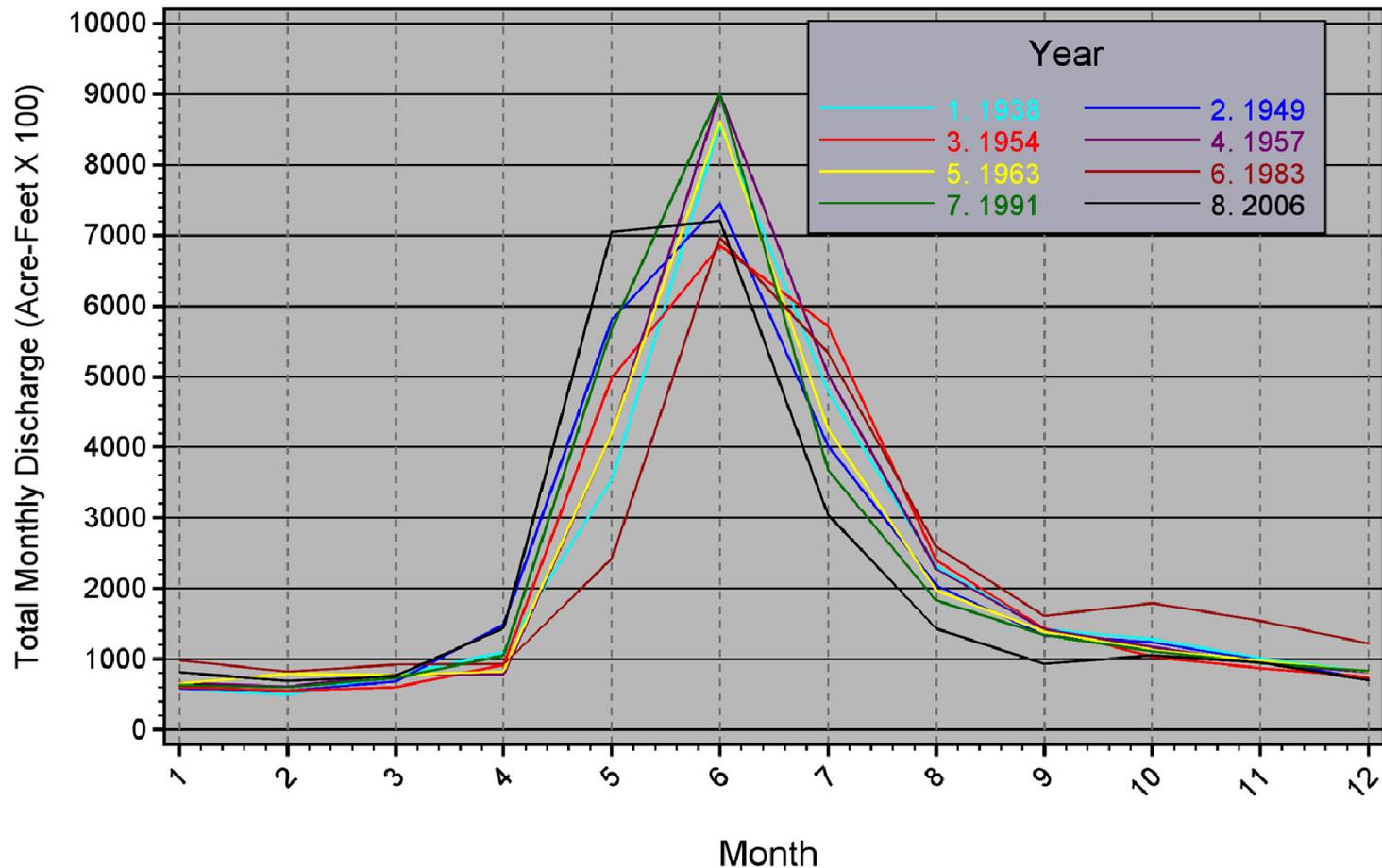
Yellowstone River at Livingston--Historic Annual Total Discharge 1930-2011



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Total Monthly Discharge Volume: Yellowstone River at Livingston, Montana

Years within 5 % of annual 50th percentile flow (Acre-Feet X 100)



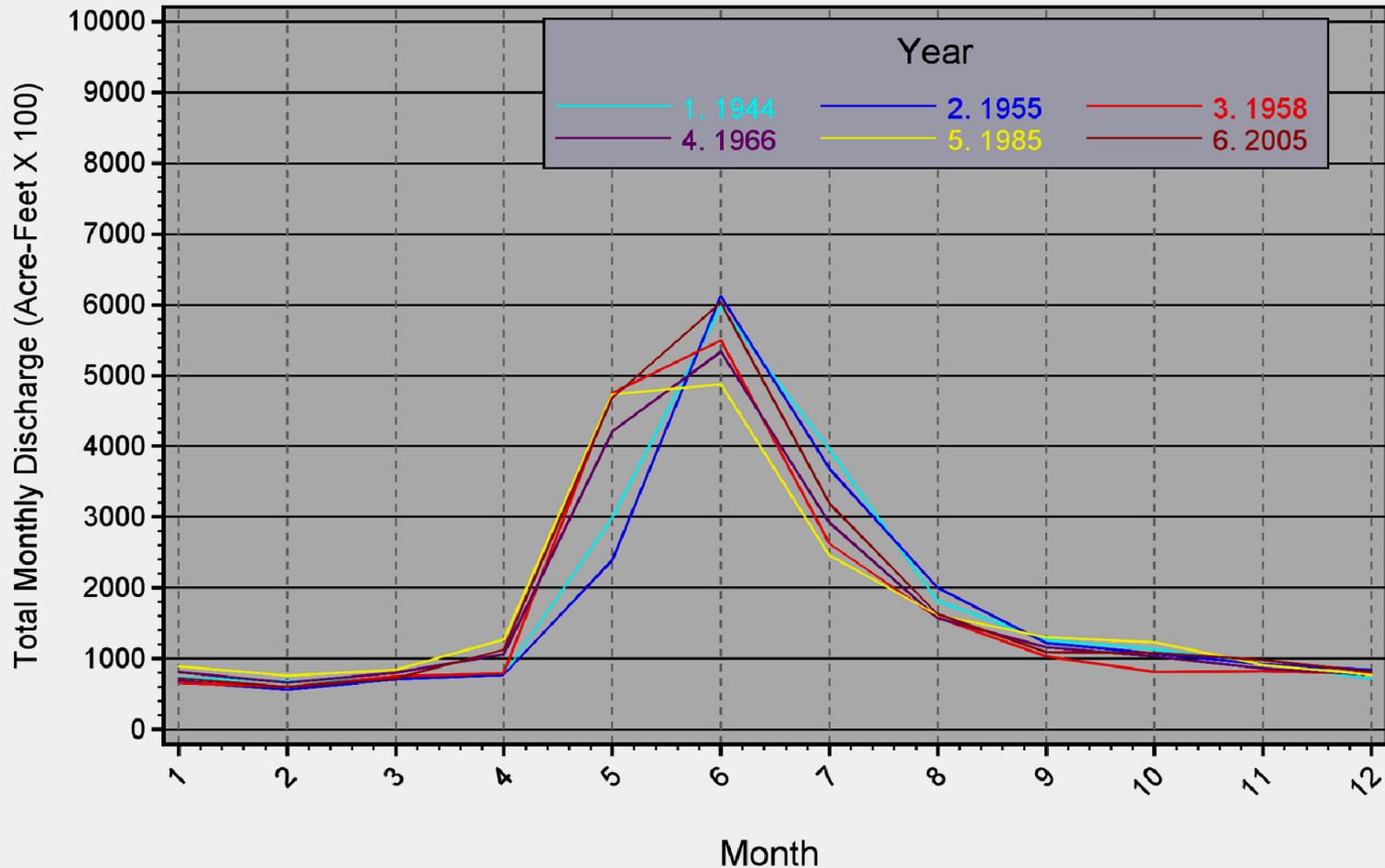
(DNRC Water Resources Division March 2013: Streamflow data retrieved from U.S. Geological Survey, National Water Information System (NWIS) database.)



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Total Monthly Discharge Volume: Yellowstone River at Livingston, Montana

(Years within 5 % of annual 20th percentile flow (Acre-Feet X 100))



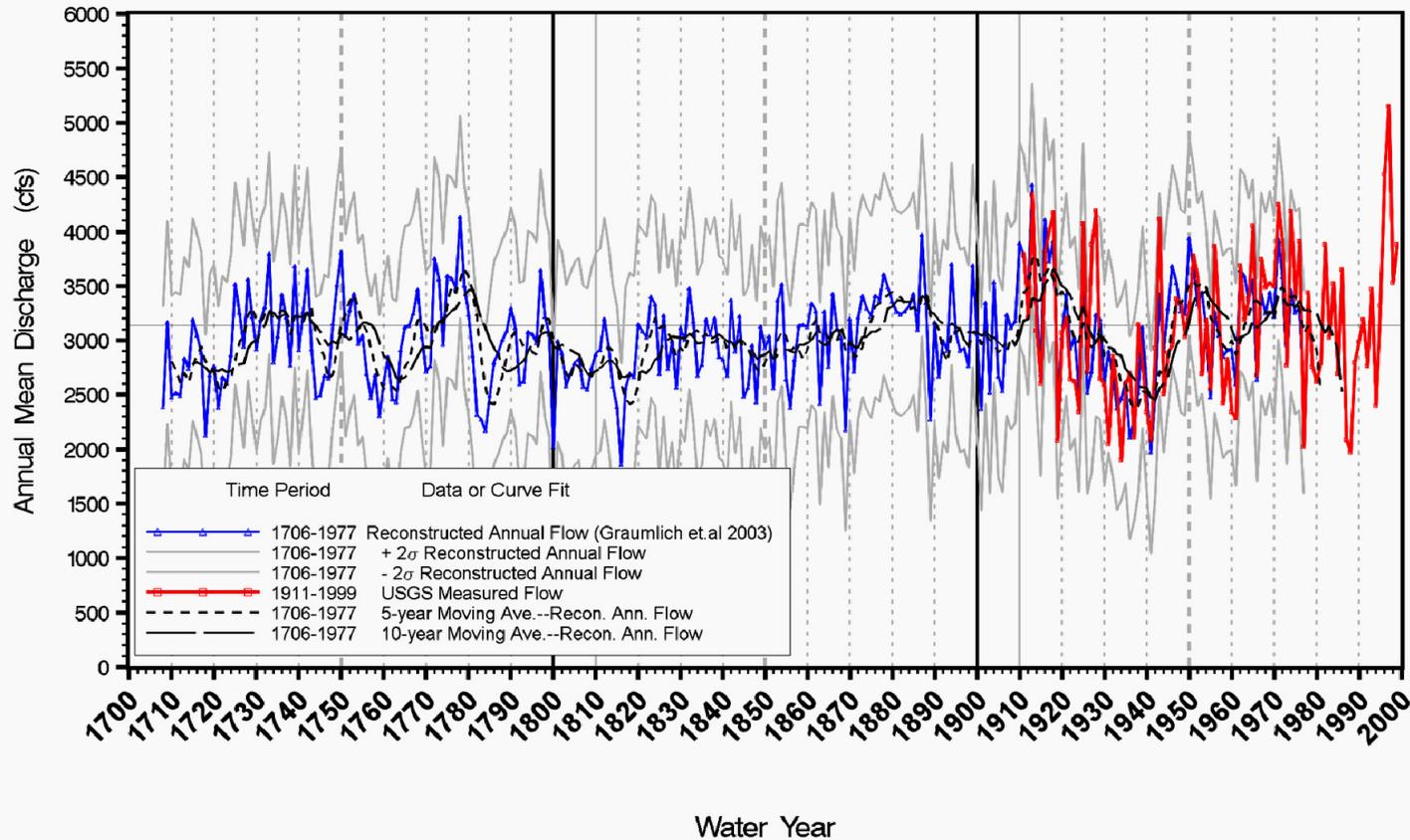
(DNRC Water Resources Division March 2013; Streamflow data retrieved from U.S. Geological Survey, National Water Information System (NWIS) database.)



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Climate and Discharge Variability – Corwin Springs

**Figure . Reconstructed (1706 to 1977) and Measured (1911-1999) Annual Runoff by Water Year:
Yellowstone River near Corwin Springs, Montana (U.S. Geological Survey Station 06191500)**



Flow reconstruction by Graumlich et al. 2003 (Upper Yellowstone River flow and teleconnections with Pacific Basin climate variability during the past three centuries. Climatic Change 59: 245-262). Annual streamflow 1706-1977 reconstructed by Graumlich et al. (2003) using upper Yellowstone tree-ring width chronologies and extra-regional climate parameters. Data Source: Reconstructed Annual Flow, -2 and + 2 Standard Deviation of Flow, and USGS Measured Flow = Graumlich, L.J., et al., Upper Yellowstone River Flow Reconstruction International Tree-Ring Data Bank. IGBP PAGES/World Data Center for Climatology, Data Contribution Series #2002-074. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA. Five and ten-year moving averages computed from retrieved data. (DNRC Water Resources Division, Helena, MT.)



Water Management

- Dams, Reservoirs and Storage
- Concept of Water Budget / Water Account



How is Yellowstone Water Managed ? Who manages it ?

**DNRC Water Right Adjudication
and Administration**

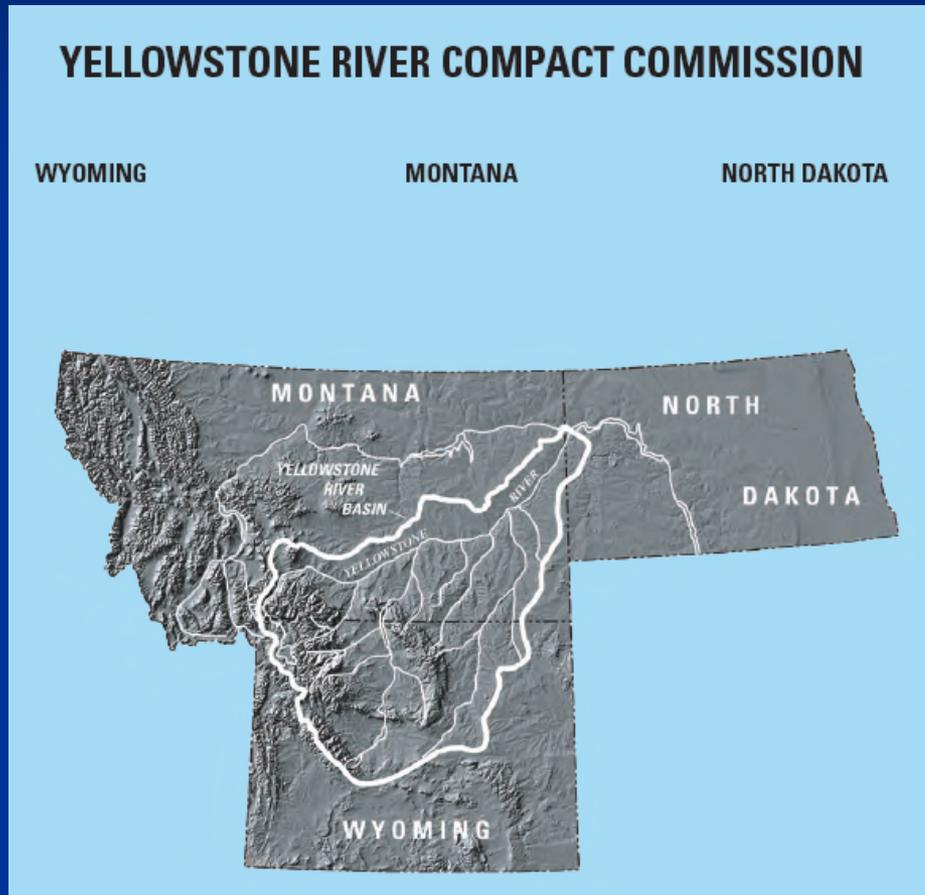
DNRC Water Management Bureau
--Statute: Treaties, Compacts,
--Watershed Groups

--MANY other state and federal
agencies, canal companies, and
water user groups

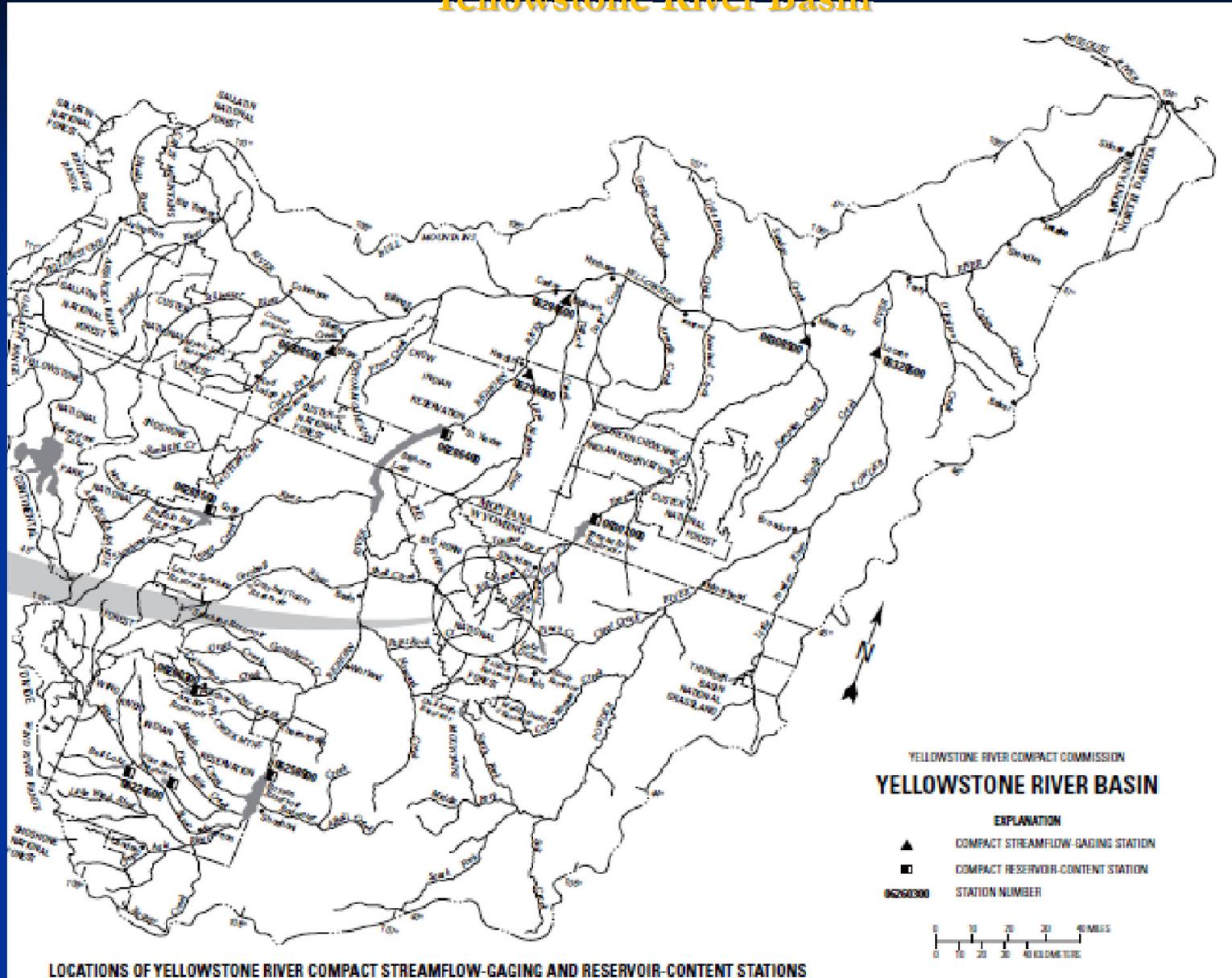


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Dams, Reservoirs and Storage



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LOCATIONS OF YELLOWSTONE RIVER COMPACT STREAMFLOW-GAGING AND RESERVOIR-CONTENT STATIONS



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Water Storage Reservoirs in Montana Portion of Yellowstone River Basin (capacity greater than 1000 acre-feet)

| RESERVOIR | OWNER | SOURCE | DAM SURFACE AREA (AC) | CAPACITY (AC-FEET) | PRIORITY | VOL | USE |
|------------------------|-------|--------------------|-----------------------|--------------------|------------|-----------|---------------|
| WILLOW CREEK RESERVOIR | USBIA | LODGE GRASS CREEK | 36,188 | 22,900 | 1868/05/07 | 22,900 | IRRIGATION |
| GLACIER LAKE | DNRC | ROCK CREEK | 166 | 4,200 | 1934/05/14 | 4,753 | SALE |
| COONEY RESERVOIR | DNRC | RED LODGE CREEK | 862 | 28,230 | 1934/05/14 | 30,937 | SALE |
| COONEY RESERVOIR | DNRC | TRIB. VOLNEY CREEK | 862 | | 1937/04/01 | 11,635 | SALE |
| COONEY RESERVOIR | DNRC | ROCK CREEK | 862 | | 1937/04/01 | 8,000 | SALE |
| YELLOWTAIL DAM | USBR | BIGHORN RIVER | 17,298 | 1,427,840 | 1961/05/05 | 1,116,000 | Multi/F,P,I,R |
| YELLOWTAIL AFTERBAY | USBR | BIGHORN RIVER | | 3,141 | 1961/05/05 | 3,141 | Multi/F,P,I,R |
| TONGUE RIVER RESERVOIR | DNRC | TONGUE RIVER | 3,600 | 79,071 | 4/21/1937 | 134,316 | SALE |



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Table 10. Water-year-end contents for Yellowstone River Compact reservoirs¹ or lakes.

[Contents are in acre-feet. Reservoirs or lakes are listed in alphabetical order by drainage basin. Abbreviation: e, estimated]

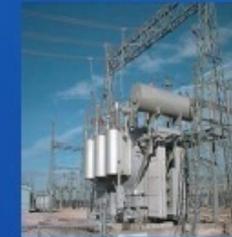
| Reservoir or lake name | Pre-compact 1950 water right | Post-compact 1950 water right | Usable contents | Usable contents on Sept. 30, 2010 | Usable contents on Sept. 30, 2009 | Change in usable contents ² |
|--|---------------------------------|----------------------------------|--------------------|--------------------------------------|--------------------------------------|---|
| Bighorn River Basin | | | | | | |
| (Lake) Adelaide Reservoir ³ | 1,450 | 3,320 | 4,770 | 980 | 2,270 | -1,290 |
| Anchor Reservoir ⁴ | 0 | 9,250 | 17,410 | 350e | 325 | 25 |
| Bighorn Lake ⁴ | 0 | 1,312,000 | 1,312,000 | 944,900 | 1,045,000 | -100,100 |
| Boysen Reservoir ⁴ | 757,900 | 0 | 701,500 | 599,100 | 619,500 | -20,400 |
| Buffalo Bill Reservoir ⁴ | 456,600 | 187,900 | 644,500 | 485,500 | 486,000 | -500 |
| Bull Lake ⁴ | 77,040 | 0 | 77,040 | 65,120 | 79,040 | -13,920 |
| Greybull Valley Reservoir ³ | 0 | 33,170 | 33,170 | 4,160 | 1,280 | 2,880 |
| Pilot Butte Reservoir ⁴ | 34,600 | 0 | 34,600 | 14,300 | 16,000 | -1,700 |
| Sunshine Reservoir ³ | 52,990 | 0 | 52,990 | 52,340 | 47,760 | 4,580 |
| Lower Sunshine Reservoir ³ | 0 | 58,750 | 58,750 | 25,060 | 35,570 | -10,510 |
| Powder River Basin | | | | | | |
| Cloud Peak Reservoir ³ | 3,400 | 172 | 3,570 | 3,570 | 3,570 | 0 |
| Dull Knife Reservoir ³ | 0 | 4,320 | 4,350 | 1,180 | 1,520 | -340 |
| Healy Reservoir ³ | 0 | 5,140 | 5,140 | 3,970 | 4,340 | -370 |
| Kearney Reservoir ³ | 1,850 | 4,470 | 6,320 | 2,190 | 2,500 | -310 |
| Lake DeSmet ³ | 37,520 | 197,500 | 235,000 | 203,600 | 184,500 | 19,100 |
| Muddy Guard Reservoir ³ | 0 | 2,340 | 2,340 | 840 | 1,380 | -540 |
| Tie Hack Reservoir ³ | 1,650 | 788 | 2,440 | 2,440 | 2,440 | 0 |
| Willow Park Reservoir ³ | 4,460 | 0 | 4,460 | 337 | 0 | 337 |
| Tongue River Basin | | | | | | |
| Bighorn Reservoir ³ | 2,750 | 1,880 | 4,630 | 357 | 956 | -599 |
| Cross Creek Reservoir ³ | 0 | 798 | 798 | 78 | 253 | -175 |
| Dome Reservoir ^{3,5} | 1,840 | 188 | 2,030 | 993 | 1,760 | -767 |
| Granger Reservoir ³ | 146 | 0 | 146 | 0 | 0 | 0 |
| Last Chance Reservoir ³ | 90 | 0 | 90 | 0 | 0 | 0 |
| Martin Reservoir ³ | 561 | 0 | 561 | 0 | 0 | 0 |
| Park Reservoir ³ | 7,350 | 3,020 | 10,360 | 3,790 | 4,160 | -370 |
| Sawmill Lakes Reservoir ³ | 0 | 1,280 | 1,280 | 690 | 989 | -299 |
| Tongue River Reservoir ⁶ | 79,070 | 0 | 79,070 | 51,100 | 48,710 | 2,390 |
| Twin Lakes Reservoir ^{3,7} | 1,180 | 2,220 | 3,400 | 2,200 | 2,350 | -150 |
| Weston Reservoir ³ | 370 | 0 | 370 | 0 | 0 | 0 |
| Willits Reservoir ³ | 79 | 0 | 79 | 0 | 0 | 0 |



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**OPERATIONS - A BALANCING
ACT AMONG THE COMPETING
INTERESTS**

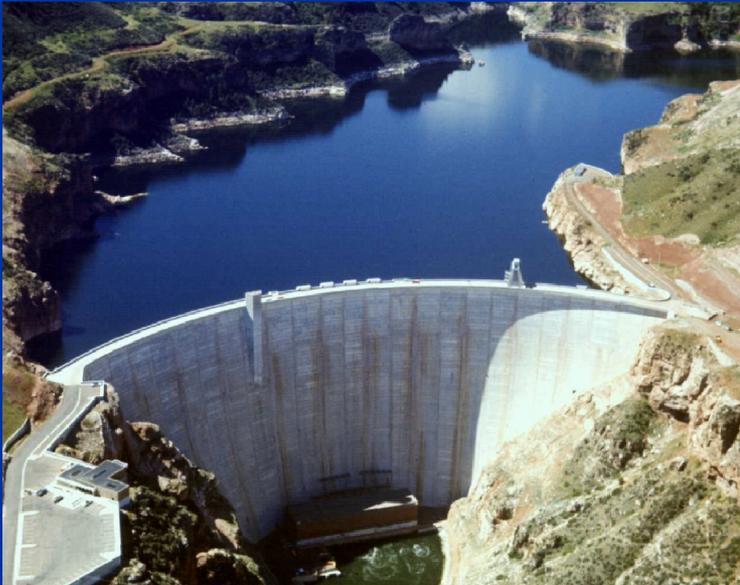


RECLAMATION



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Yellowtail Dam

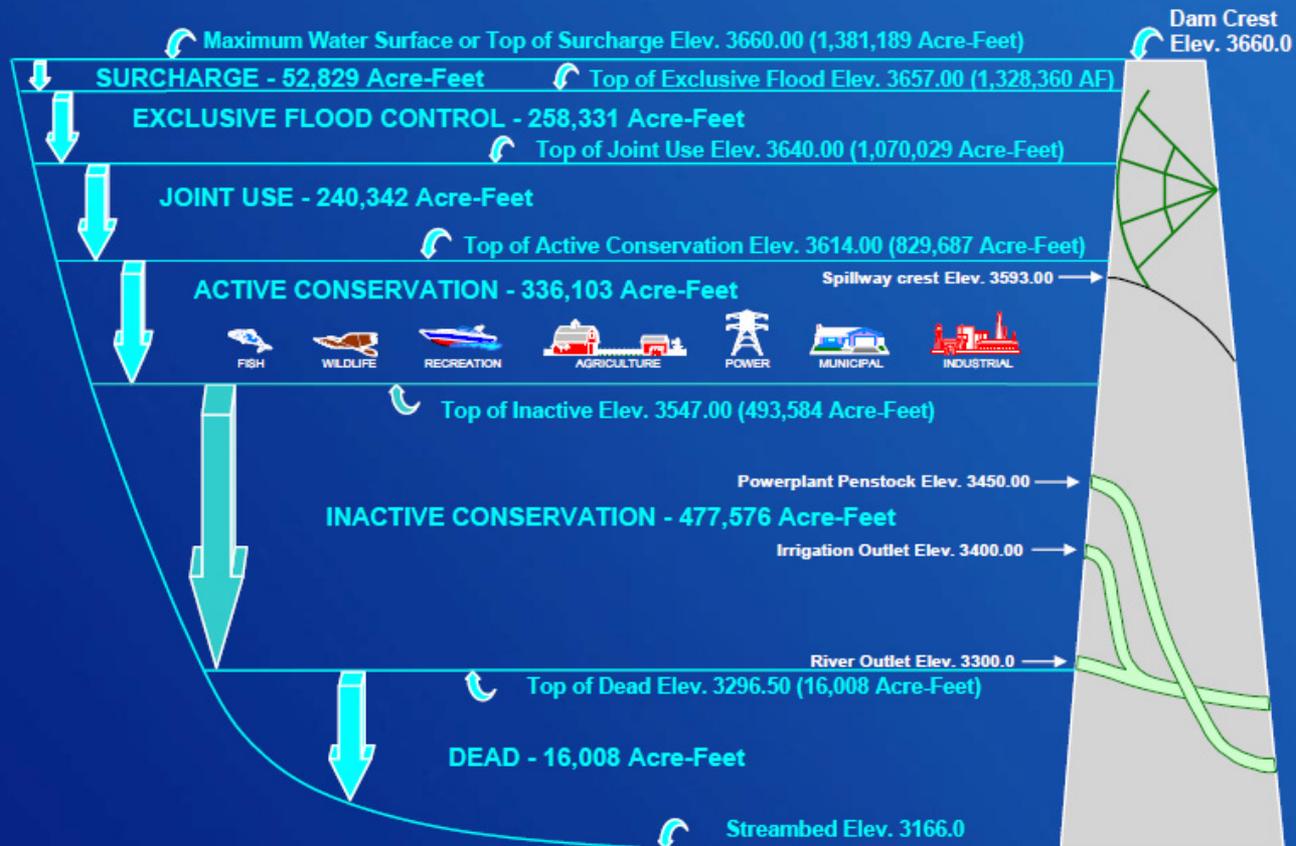


Bighorn Reservoir



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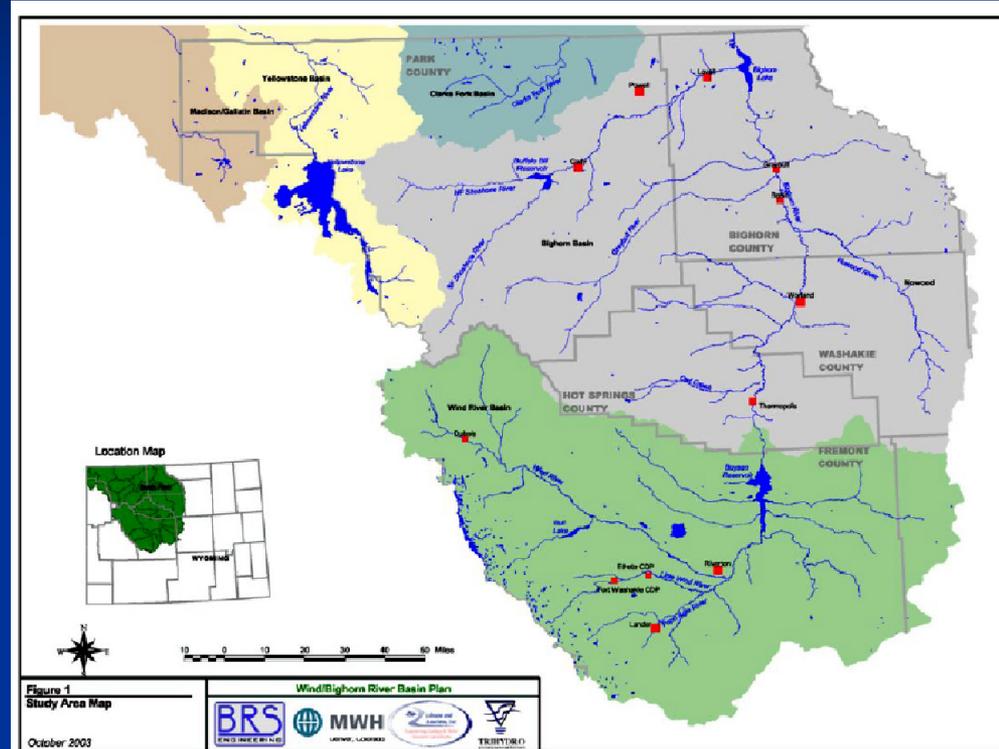
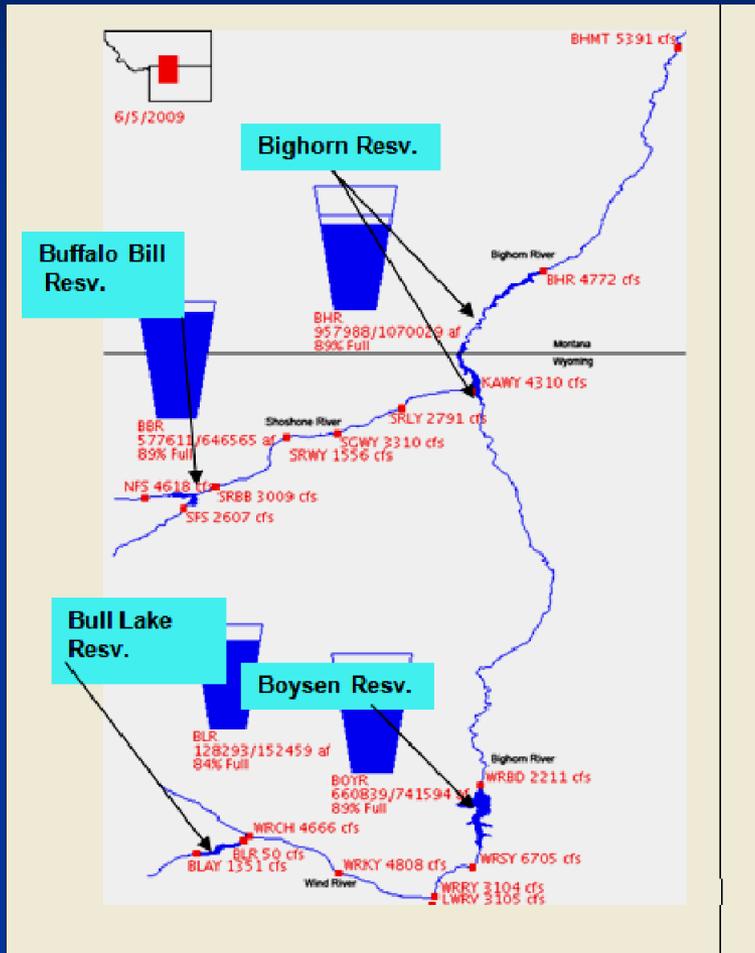
BIGHORN RESERVOIR ALLOCATIONS



RECLAMATION



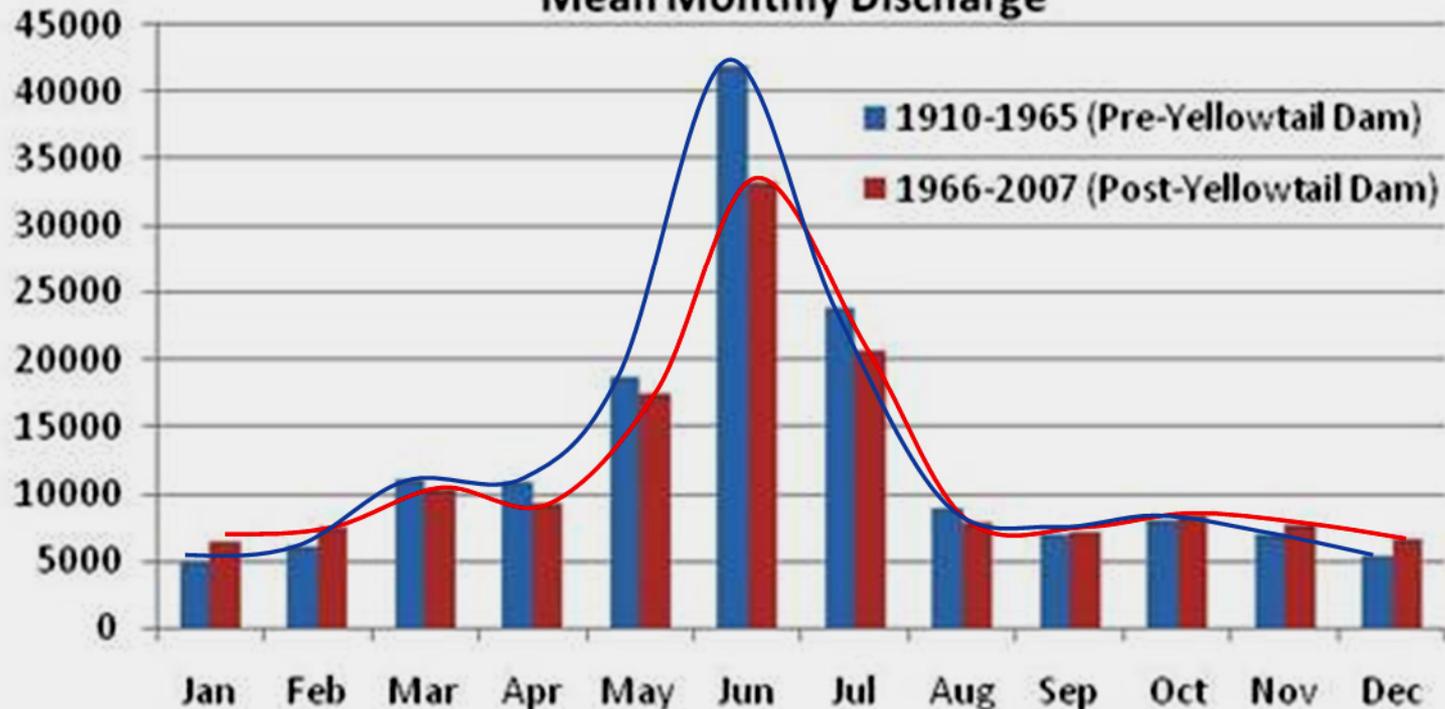
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Yellowstone River Cumulative Effects Assessment

Yellowstone River at Sidney

Mean Monthly Discharge



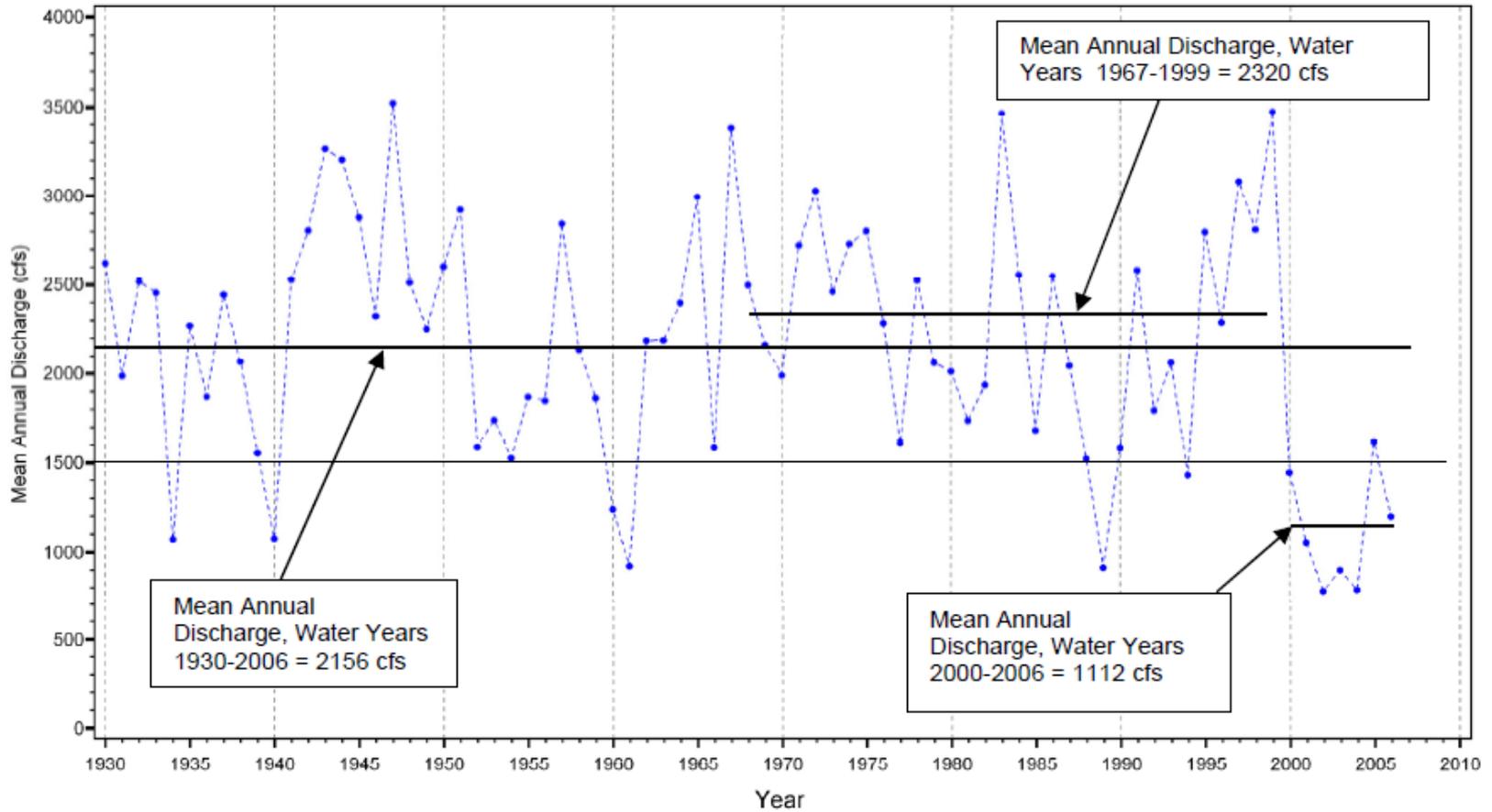
Source: Yellowstone River Conservation District's Council (YRCDC)



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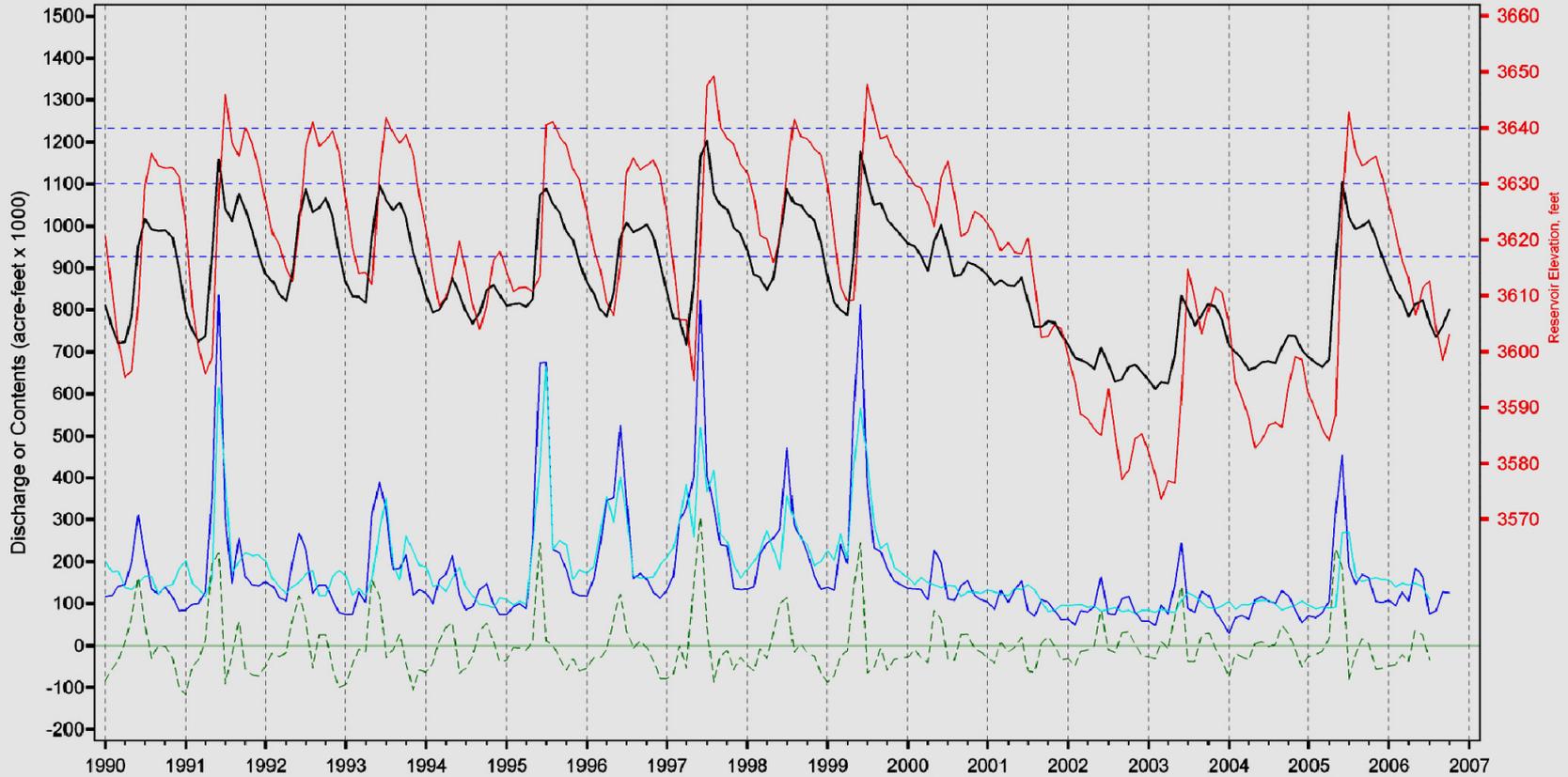
Yellowstone River Basin

Figure 3. Mean Annual Discharge of Bighorn River at Kane, Wyoming: Water Years 1930 - 2006



2015 Montana Water Supply Initiative Yellowstone River Basin

Figure 4. Big Horn Reservoir Inflow, Outflow, Contents and Elevation, 1990 to 2006



Big Horn Reservoir Operations: 1990 to 2006

| | |
|---|--|
| <p>— 1. Computed Inflow (ac-ft, monthly total x 1000)</p> <p>— 3. Outflow (Big Horn R nr StXavier—Ac-ft x 1000)</p> | <p>— 2. End-of-Month Reservoir Contents (Ac-ft x 1000)</p> <p>- - - 4. Inflow - Outflow (Ac-ft x 1000)</p> |
|---|--|



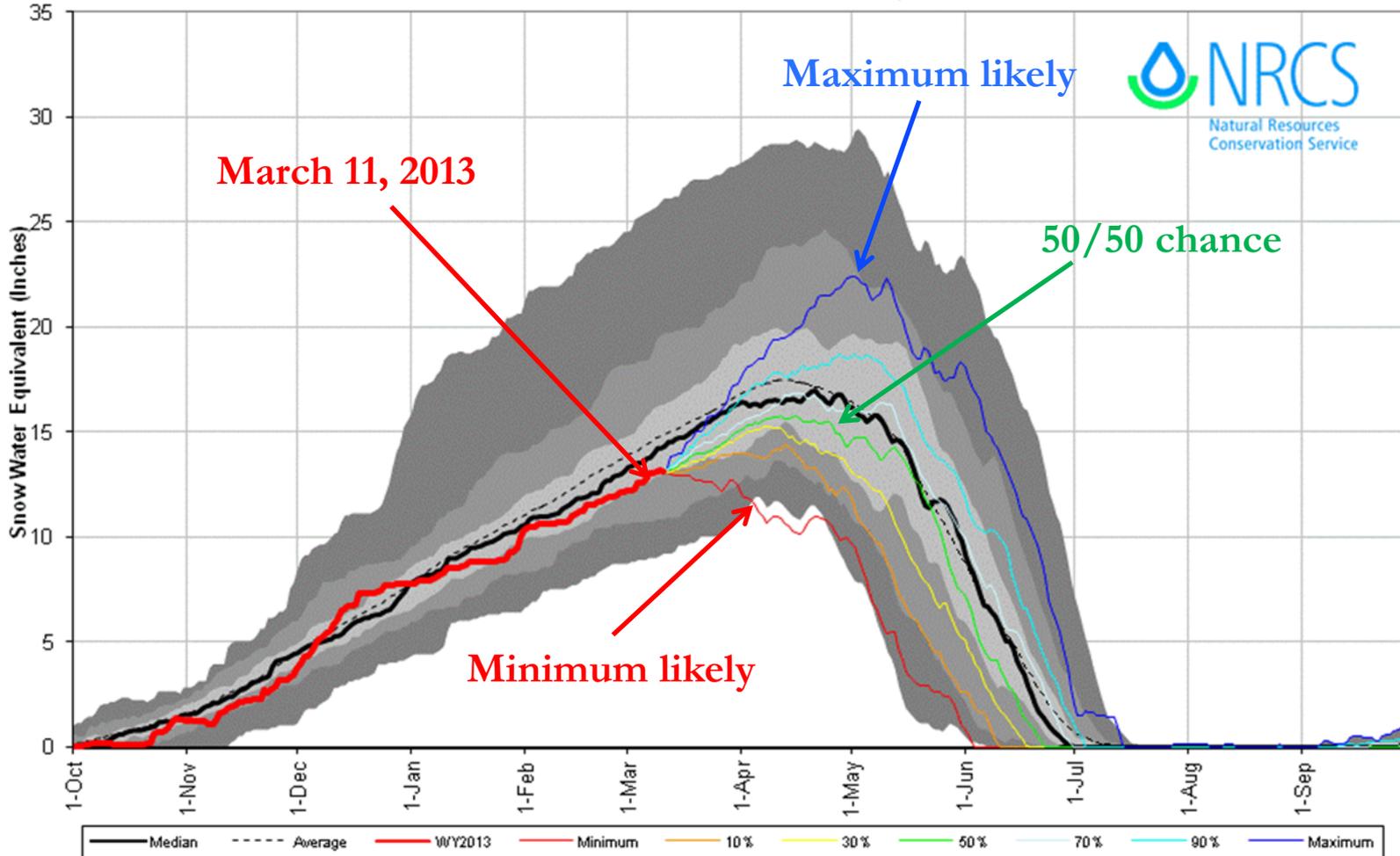
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Yellowstone River Basin

NRCS Water Supply Forecasting is Critical to Management of Montana's Water

Upper Yellowstone River Basin with Non-Exceedence Projections

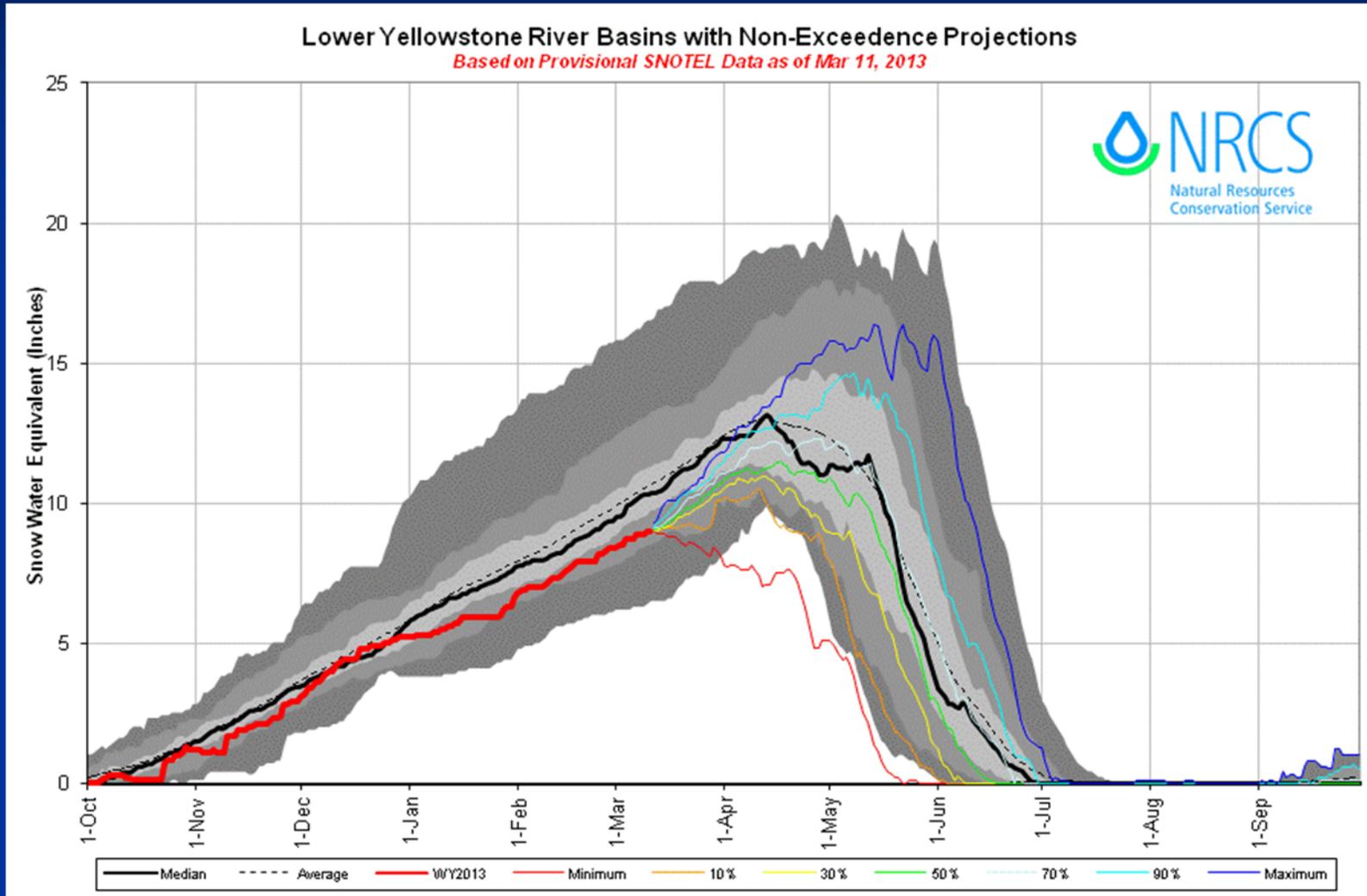
Based on Provisional SNOTEL Data as of Mar 11, 2013



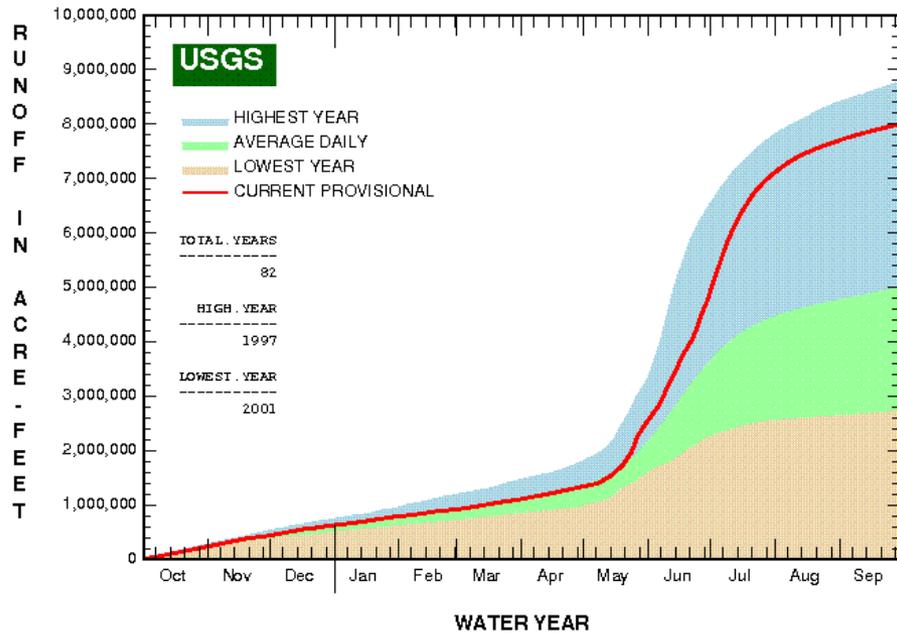
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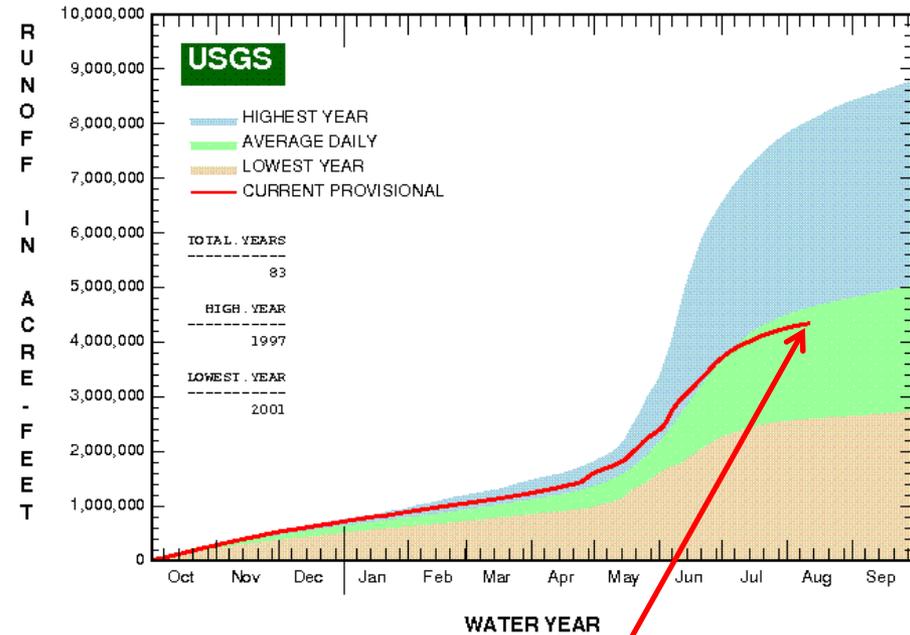
NRCS Water Supply Forecasting is Critical to Management of Montana's Water



2015 Montana Water Supply Initiative Yellowstone River Basin



Yellowstone River at Billings MT



Yellowstone River at Billings MT

Water Year 2011

Water Year 2012



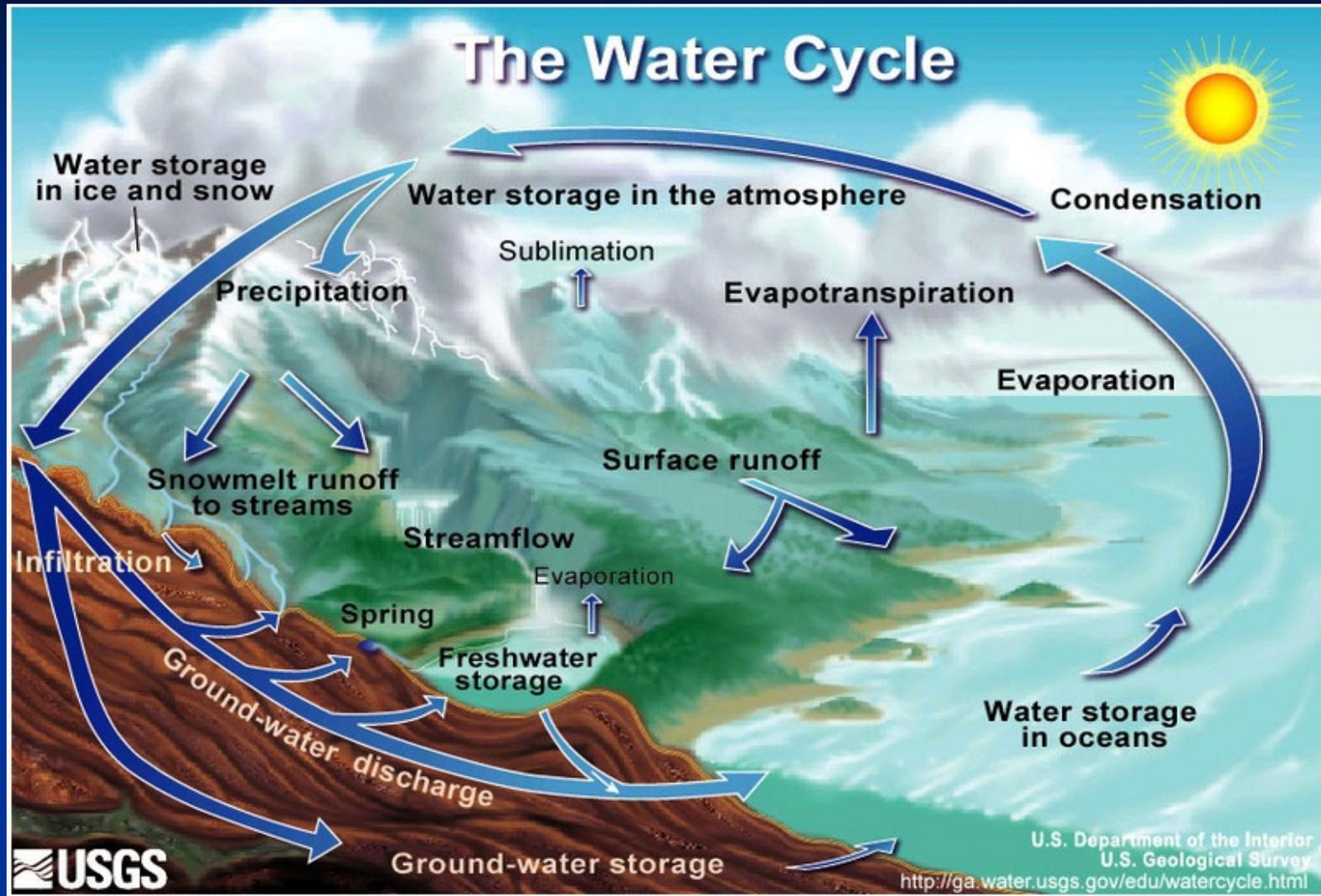
Concept of Water Budget

$$\begin{aligned} & \left(\text{Water In} - \text{Water Out} \right) = \text{Water Balance} \\ & \underbrace{\left(\text{Precip} + \text{Inflow} \right)}_{\text{Water In}} - \underbrace{\left(\text{Cons. Use} + \text{Outflow} \right)}_{\text{Water Out}} = \text{Change in Storage} \end{aligned}$$

Because water can be stored as groundwater and in surface reservoirs, the Water Balance represents the change in stored water over time (daily, monthly, annual).



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$$(PRECIP + INFLOW) - (CONSUMPTIVE USE + OUTFLOW) = \text{Change In Storage}$$

$$(P + IN) - (C + OUT) = \Delta S$$

P = rain and snow

IN = surface water or groundwater inflow

C = evaporation and transpiration (ET)

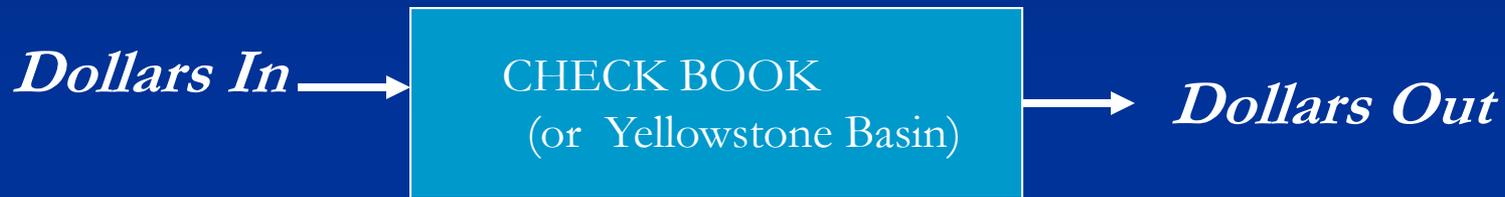
OUT = surface water or groundwater outflow

ΔS = *change water stored in watershed*

$$P + Q_{in}^{sw} + Q_{in}^{gw} = ET^{sw} + ET^{gw} + ET^{uz} + \Delta S^{sw} + \Delta S^{snow} + \Delta S^{uz} + \Delta S^{gw} + Q_{out}^{gw} + RO + Q^{bf}$$



Water Budget is like a checking-account



$$\textit{Account Balance} = \$In - \$Out$$

Over time (monthly or when balanced) the account balance also represents the change in \$ stored in the account

When an entire enterprise uses the same checking account for all finances, things quickly get complicated:



Problems: Multiple parties writing checks; mistakes, checks/deposits not recorded; simultaneous withdrawals

The more “users”, the harder it is to account for dollars in and dollars out and the variation in irregular sources of income and expenditures.

CONSEQUENCES—more bank charges (unless there are many more \$ coming in, than going out), you never know how much you have in the bank? Can't plan, make reliable investments, meet obligations.



2015 Montana Water Supply Initiative
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**How is the Yellowstone
Water Account (Budget)
Managed ?
Who manages it ?**

**DNRC Water Right Adjudication
and Water Court Administration provide
legal framework – but many important
participants:**

- All Water Users (all beneficial uses)**
- State, Federal Agencies (Clean Water Act), Tribes**
- DNRC Water Management Bureau**
- Statute: Treaties, Compacts,**
- Watershed Groups**

