Glen Canyon Dam Adaptive Management Work Group
Agenda Item Form
February 15-16, 2017

Agenda Item

Analysis of Water Losses and Impacts to the Grand Canyon Ecosystem of the "Fill Mead First" Proposal

Purpose of Agenda Item

To inform AMWG members of the natural science issues of the "Fill Mead First" proposal, and how water storage rules for Lake Powell and Lake Mead affect the Grand Canyon ecosystem and its future.

Action Requested

Information item only; we will answer questions but no action is requested.

Presenter

John (Jack) C. Schmidt, Watershed Sciences Department, Utah State University

Previous Action Taken

N/A

Relevant Science

See below.

Summary of Presentation and Background Information

The Fill Mead First proposal of the Glen Canyon Institute (http://www.glencanyon.org/glen_canyon/fill-mead-first) has been widely reported as an alternative strategy for allocating reservoir storage between Lake Powell and Lake Mead. Although the concept has been discussed from legal, administrative, and policy perspectives, there have been few publically available analyses of the natural science issues associated with water losses and impacts on the Grand Canyon ecosystem. Dr. Schmidt completed such an analysis in 2016 and released a report through the Utah State University Center for Colorado River Studies <https://qcnr.usu.edu/wats/colorado_river_studies/>. The results of this analysis shed light on how water storage rules for Lake Powell and Lake Mead affect the Grand Canyon ecosystem and its future.

The Fill Mead First (FMF) plan would establish Lake Mead reservoir as the primary water storage facility of the main-stem Colorado River and would relegate Lake Powell reservoir to a secondary water storage facility to be used only when Lake Mead is full. The FMF plan would be implemented in three phases. Phase I would involve lowering Lake Powell to the minimum elevation at which hydroelectricity can still be produced (called minimum power pool elevation): 3490 ft asl (feet above sea level). Phase II of the FMF plan would involve lowering Lake

Powell to dead pool elevation (3370 ft asl), abandoning hydroelectricity generation, and releasing water only through the river outlets. Implementation of Phase III would necessitate drilling new diversion tunnels around Glen Canyon Dam in order to eliminate all water storage at Lake Powell. In this presentation, Dr. Schmidt will identify critical details about the plan's implementation that are presently unknown. He estimates changes in evaporation losses and ground-water storage that would occur if the FMF plan was implemented, based on review of existing data and published reports. He also discusses significant river-ecosystem issues that would arise if the plan was implemented.

Implementation of Phase I of FMF would allow the flow regime of the Colorado River in Grand Canyon to be more natural, but only if hydropower generation does not follow daily and weekly demands. Implementation of Phase II of FMF would unavoidably create a less natural flow regime. The primary limitation to re-establishing a natural flow regime is the capacity of the facilities that release reservoir water downstream to the Grand Canyon ecosystem. The capacity of the penstocks that route water to the power plant is ~31,500 ft^3/s (cubic feet per second), and an additional ~15,000 ft^3/s can be released through the river outlets when the reservoir is at minimum power pool. However, the penstocks cannot be used when the reservoir is below minimum power pool, and the capacity of the river outlets decreases as reservoir elevation drops; the capacity of the river outlets is less than 5000 ft^3/s when the reservoir is near dead pool elevation. Thus, the largest releases from Lake Powell could only be ~45,000 ft^3/s during Phase I, even though typical incoming floods to Lake Powell exceed 50,000 ft^3/s in most years. If Phase II was implemented and an attempt was made to maintain the reservoir at dead pool, releases downstream could be only 5000 ft^3/s. Whenever incoming floods to Lake Powell exceeded this flow rate, the temporarily drained reservoir would partially refill, especially during each year's spring snowmelt season. In wet years, reservoir elevation would rise more than 100 ft to minimum power pool elevation, and floods of 45,000 ft^3/s could occur, but only for as long as the reservoir remained above 3490 ft asl. ***A natural flow regime is likely to exist most of the time if Phase III of FMF was implemented.***

A renewable supply of fine sediment is necessary to maintain Grand Canyon's eddy sandbars that are used by river runners, create the architecture of aquatic habitat, and serve as a source of fine sediment to be redistributed by winds upslope to help protect archaeological sites. However, Phase I or Phase II would not change the existing condition of fine-sediment deficit that exists in Grand Canyon today, because ***water released from a partially drained Lake Powell in Phase I or Phase II would be devoid of fine sediment. Impacts to the aquatic and riparian ecosystem, including to the existing population of endangered humpback chub, are potentially significant and would have to be monitored and managed adaptively***.

Dr. Schmidt estimates that there would be a small net decrease in total reservoir evaporation if Phase I or Phase II were implemented in comparison to present conditions. Implementation of FMF would decrease the combined surface area of the water stored in both reservoirs, and the evaporation rate from Lake Mead is not much more than from Lake Powell. However, the magnitude of the savings is less than the natural range in variability in evaporation. The rate of evaporation loss from Lake Mead has been measured by the U. S. Geological Survey (USGS) in a state-of-the-science program since 2010 (Moreo, 2013, 2015), and these measurements show that the annual evaporation loss rate is ~6.0 ft/yr and has varied between 5.5 and 6.4 ft/yr. There are no recent state-of-the-science measurements at Lake Powell; the average evaporation rate between 1965 and 1979 was 5.7 ft/yr and varied between 4.9 and 6.5 ft/yr. ***For purposes of public policy***

discussion, we conclude that there would be no change in evaporation losses if FMF was implemented.

Movement of reservoir water into the ground-water system that surrounds Lake Powell is inevitable. Most of the ground water that has already moved into storage would return to the Colorado River during a period of decades to centuries after FMF was implemented. A small proportion of the reservoir water that has moved into the surrounding bedrock has been a true loss from Lake Powell, but this water has seeped around Glen Canyon Dam and returned to the Colorado River immediately downstream from the dam. ***Based on the best estimates of Thomas (1986), the long-term future rate of movement of ground water into the surrounding bedrock is likely to be less than ~0.05 million af/yr (~50,000 af/yr), and would decline to less ~0.03 million af/yr (~30,000 af/yr) after mid-21st century.***

Assuming that movement of reservoir water into ground-water storage surrounding Lake Mead is small – an estimate suggested by water balance calculations but not yet verified by independent measurements of ground-water flow at wells – ***the projected water savings by implementing FMF would be less than ~0.05 million af/yr (~50,000 af/yr).*** It is a matter of public policy debate whether or not this magnitude of savings is sufficiently large to justify immediate reconsideration of many administrative and legal agreements concerning storage of water in Lake Powell and Lake Mead. At some time in the future, however, this magnitude of water savings might be viewed as sufficiently large to be worth serious engineering and scientific analysis and policy discussion. ***Now is the time to initiate new measurement programs of losses at Lake Powell and Lake Mead so that future policy discussions have access to less uncertain data regarding evaporation and ground-water storage.*** Initiation of a new measurement program of evaporation at Lake Powell, continuation of the present evaporation measurement program at Lake Mead, and initiation of a new phase of ground-water monitoring and modeling at Lake Powell and perhaps at Lake Mead would inform these discussions. Establishment of new observation wells further and to the south from Lake Powell, coupled by development of modern, state-of-the-science numerical models of ground-water flow, would allow more precise estimates of future movement of reservoir water into the surrounding ground-water system. Establishment of a new gaging station to reduce uncertainty in estimating the amount of unmeasured inflow to Lake Powell would allow a more accurate water budget to be developed. In addition, implementation of FMF would have to be preceded by predictive modeling of fine-sediment redistribution within a partially drained Lake Powell so that reservoir releases would not further degrade the Grand Canyon ecosystem. Collectively, these data, analyses, and modeling tools would empower future water resource decision-makers to make informed decisions about management of Lake Powell and Lake Mead.

FILL MEAD FIRST:
a technical assessment

John C. Schmidt

with contributions from
Maggi Kraft, Daphnee Tuzlak, and Alex Walker

White Paper No. 1
Center for Colorado River Studies
Quinney College of Natural Resources
Utah State University

Executive Summary

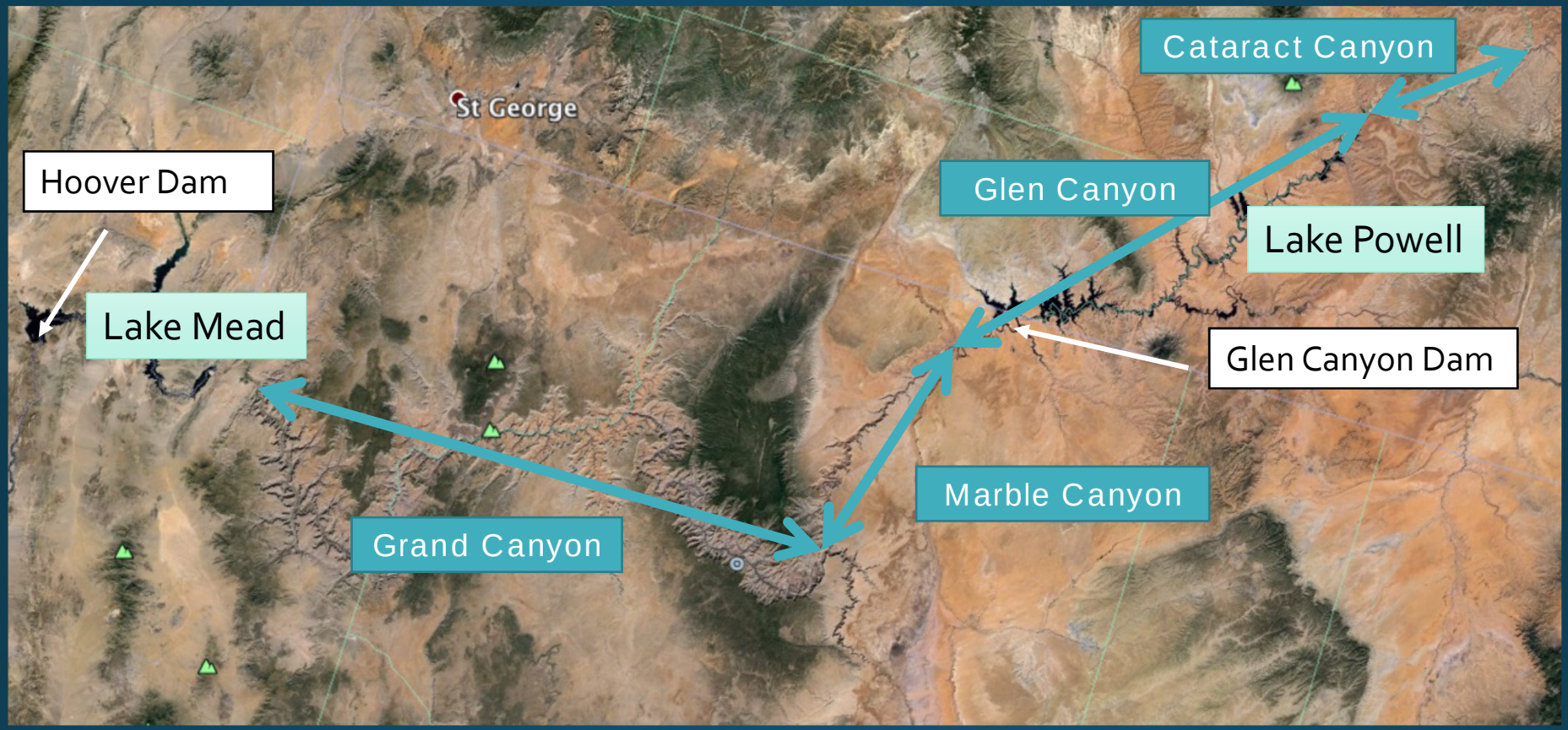
The Fill Mead First (FMF) plan would establish Lake Mead reservoir as the primary water storage facility of the main-stem Colorado River and would relegate Lake Powell reservoir to a secondary water storage facility to be used only when Lake Mead is full. The objectives of the FMF plan are to re-expose some of Glen Canyon's sandstone walls that are now inundated, begin the process of re-creating a riverine ecosystem in Glen Canyon, restore a more natural stream-flow, temperature, and sediment-supply regime of the Colorado River in the Grand Canyon ecosystem, and reduce system-wide water losses caused by evaporation and movement of reservoir water into ground-water storage. The FMF plan would be implemented in three phases. Phase I would involve lowering Lake Powell to the minimum elevation at which hydroelectricity can still be produced (called minimum power pool elevation): 3490 ft asl (feet above sea level). At this elevation, the water surface area of Lake Powell is approximately 77 mi^2, which is 31% of the surface area when the reservoir is full. Phase II of the FMF plan would involve lowering Lake Powell to dead pool elevation (3370 ft asl), abandoning hydroelectricity generation, and releasing water only through the river outlets. The water surface area of Lake Powell at dead pool is approximately 32 mi^2 and is 13% of the reservoir surface area when it is full. Implementation of Phase III would necessitate drilling new diversion tunnels around Glen Canyon Dam in order to eliminate all water storage at Lake Powell. In this paper, we summarize the FMF plan and identify critical details about the plan's implementation that are presently unknown. We estimate changes in evaporation losses and ground-water storage that would occur if the FMF plan was implement-

J. C. Schmidt

Analysis of Water Losses and Impacts to the Grand Canyon Ecosystem of the Fill Mead First Proposal

colorado_river_studies/

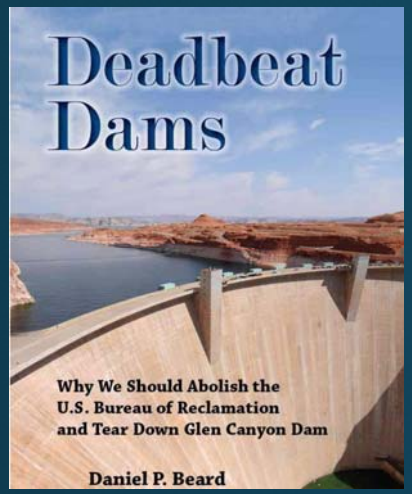
https://qcnr.usu.edu/wats/colorado_river_studies/https://qcnr.usu.edu/wats/colorado_river_studies/



Confluence of the Grand and Green Rivers to the Grand Wash Cliffs ~500 miles

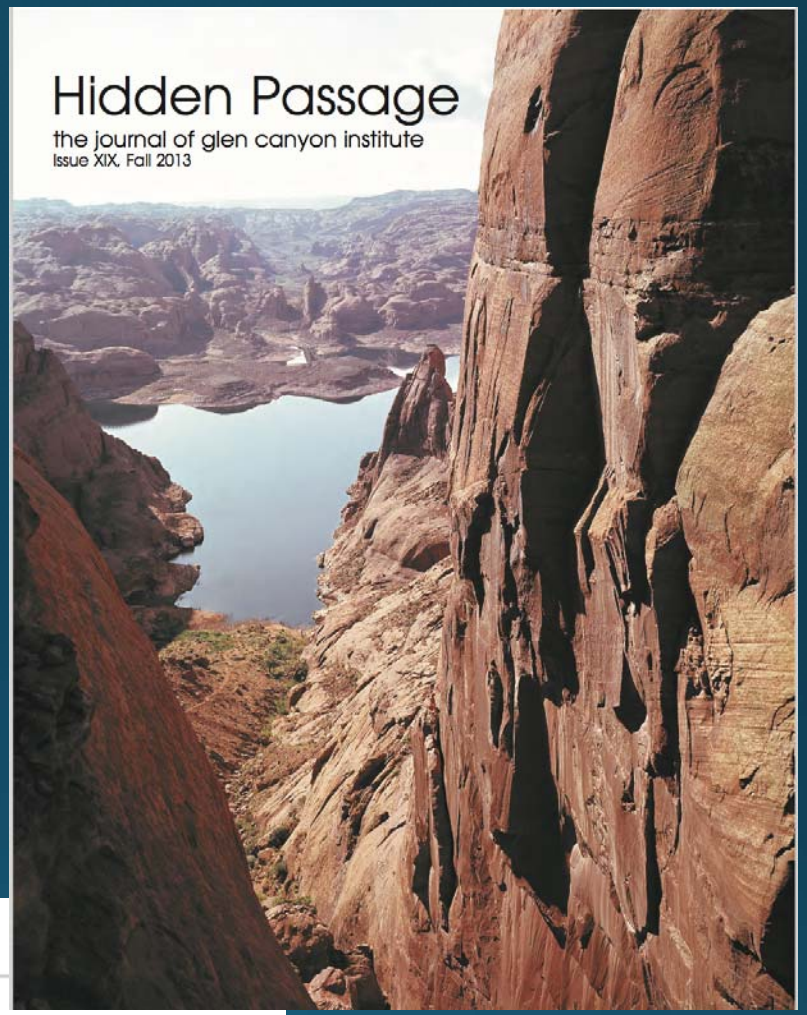
Remaining riverine segments (270 miles):

- Cataract Canyon ~15 miles
- Glen Canyon ~15 miles
- Marble Canyon ~60 miles
- Grand Canyon ~180 miles



2015

Fill Mead First -- establish Lake Mead as the primary reservoir storage facility; store water in Lake Powell only when Lake Mead is full.



2016

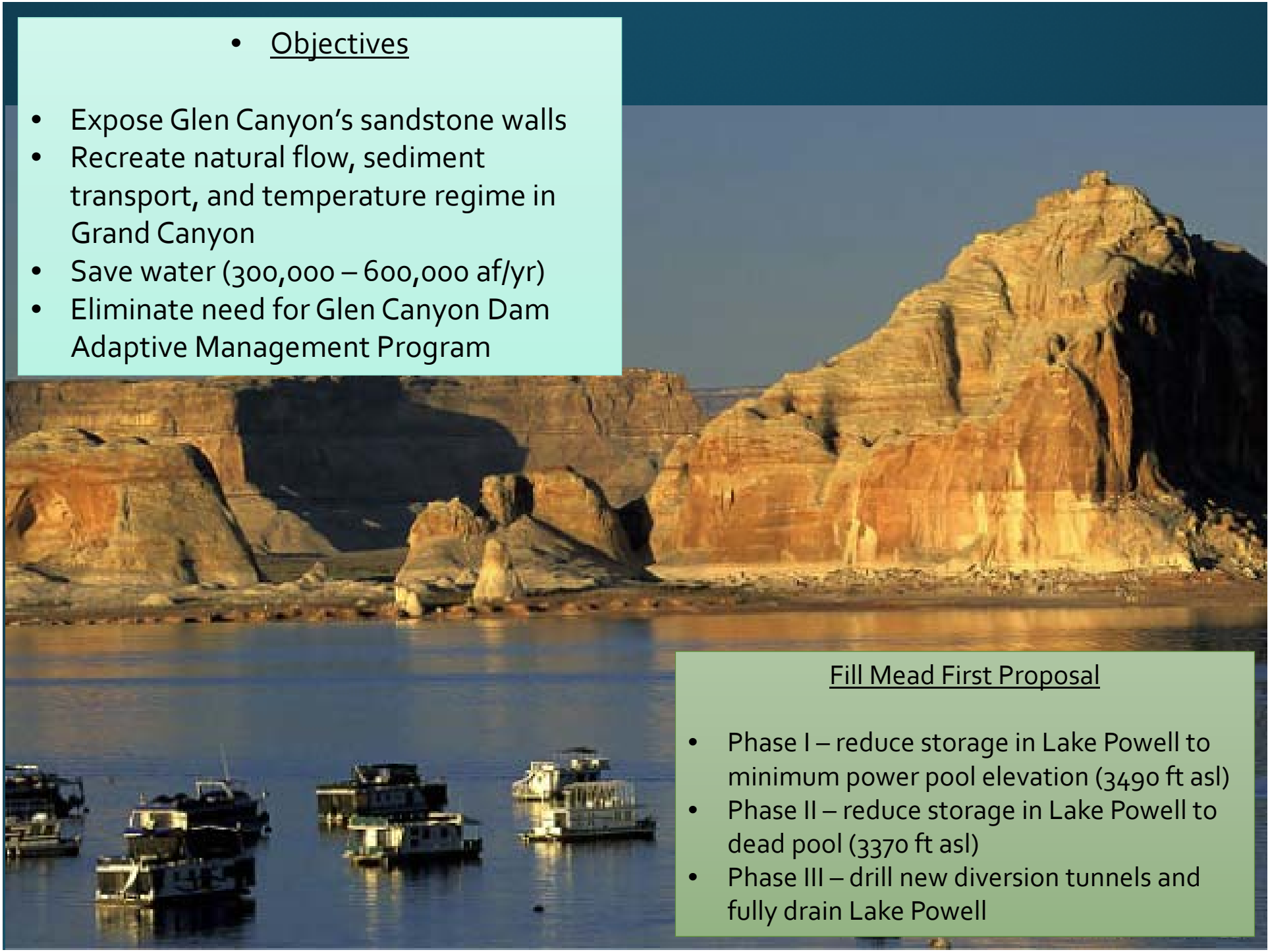
The New York Times | http://nyti.ms/1rYCQwk

Unplugging the Colorado River

Could the end be near for one of the West's biggest dams?

By ABRAHM LUSTGARTEN MAY 20, 2016

WEDGED between Arizona and Utah, less than 20 miles upriver from the Grand Canyon, a soaring concrete wall nearly the height of two football fields blocks the flow of the Colorado River. There, at Glen Canyon Dam, the river is turned back on itself, drowning more than 200 miles of plasma-red gorges and replacing the Colorado's free-spirited rapids with an immense lake of flat, still water called Lake Powell, the nation's second-largest reserve.



- <u>Objectives</u>

- Expose Glen Canyon's sandstone walls
- Recreate natural flow, sediment transport, and temperature regime in Grand Canyon
- Save water (300,000 – 600,000 af/yr)
- Eliminate need for Glen Canyon Dam Adaptive Management Program

<u>Fill Mead First Proposal</u>

- Phase I – reduce storage in Lake Powell to minimum power pool elevation (3490 ft asl)
- Phase II – reduce storage in Lake Powell to dead pool (3370 ft asl)
- Phase III – drill new diversion tunnels and fully drain Lake Powell

But it is not just the reservoir's overuse that is causing it to shrink. More than 160 billion gallons of water evaporate off Lake Powell's surface every year, enough to lower the reservoir by four inches each month. Another 120 billion gallons are believed to leak out of the bottom of the canyon each year into fissures in the earth — a loss that if tallied up over the life of the dam amounts to more than a year's flow of the entire Colorado River.

In all, these debits amount to "the largest loss of water on the Colorado River," Mr. Beard said, enough to supply some nine million people each year.

The idea is this: Since two of the nation's largest reservoirs — Lake Mead and Lake Powell, just 300 miles apart — depend on the same dwindling water source but are each less than half full, they should be combined into one. Lake Mead would be deeper, and its evaporative losses would increase. But the surface area of Lake Powell would be substantially reduced, and the evaporating water from there would be saved. Furthermore, sending the water out of Glen Canyon would move it from a valley that leaks like a sieve into one that is watertight. Evaporation losses at Mead — say plan proponents — would be more than offset by savings at Lake Powell.

In all, according to Tom Myers, a hydrologist who studied the proposal for the Glen Canyon Institute, an environmental group advocating for combining the two reservoirs, about 179 billion gallons of water would be saved each year — more than enough to supply the population of the city of Los Angeles.

"To me it is a no-brainer," said David Wegner, who studied Glen Canyon as a scientist with the Department of Interior. "You've got very few options."

New York Times, May 20, 2016

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~0.49 M af/yr evaporated from Powell

~0.37 M af/yr seepage losses

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~0.55 M af/yr saved

"To me it is a no-brainer," said David Wegner, who studied Glen Canyon as a scientist with the Department of Interior. "You've got very few options."

New York Times, May 20, 2016

Myers, 2010, Planning the Colorado River in a changing climate: reservoir loss rates in Lakes Powell and Mead and their use in CRSS. Consulting report to GCI.

Myers, 2013, Loss rates from Lake Powell and their impact on management of the Colorado River. Journal of the American Water Resources Association

Calculation of Water Savings by Myers (2010, 2013)

$$losses = E \pm G$$

$$\text{Losses}_{\text{Powell}} = E + G$$

770,000 af/yr (±60,000) = 500,000 af/yr + 270,000 af/yr (±60,000)

$$\text{Losses}_{\text{Mead}} = E + G$$

880,000 af/yr = 810,000 af/yr + 70,000 af/yr

$$\text{Losses}_{\text{Total}} = \text{Losses}_{\text{Powell}} + \text{Losses}_{\text{Mead}}$$

1,600,000 to 1,700,000 af/yr = 770,000 af/yr (±60,000) + 880,000 af/yr

Losses associated with present operating rules

~500,000 af/yr evaporation loss estimate is from Reclamation

Estimated losses

$$Losses_{Powell} = E + G$$

220,000 af/yr = 200,000 af/yr + 20,000 af/yr [FMF/Phase I]
150,000 af/yr = 130,000 af/yr + 20,000 af/yr [FMF/Phase II]

$$Losses_{Mead} = E + G$$

1,170,000 af/yr = 1,100,000 af/yr + 70,000 af/yr

$$Losses_{Total} = Losses_{Powell} + Losses_{Mead}$$

1,400,000 af/yr = 220,000 af/yr + 1,170,000 af/yr [FMF Phase I]
1,300,000 af/yr = 150,000 af/yr + 1,170,000 af/yr [FMF Phase II]

$$Saving = Losses_{Current} - Losses_{FMF}$$

300,000 af/yr = 1,700,000 af/yr - 1,400,000 af/yr [FMF Phase I]
400,000 af/yr = 1,700,000 af/yr - 1,300,000 af/yr [FMF Phase II]

Myers, (2010, 2013a, 2013b)

Note: estimate of 600,000 af/yr can only be replicated by rounding up (and down) at each stage in calculation in a way that biases the result towards savings under FMF

- **A water budget is the only way to compare losses at Lake Powell and Lake Mead**

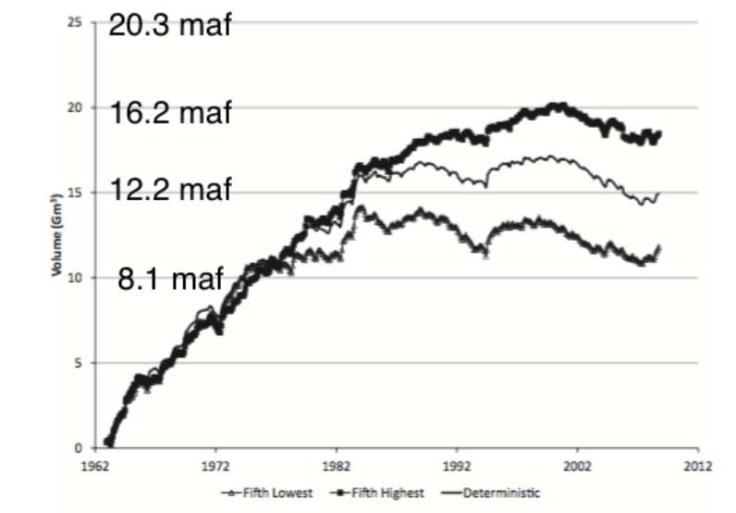
- Reclamation no longer uses the water-budget approach in 24-month planning of Lake Powell operations

- Reclamation uses a water-budget approach in long-term planning and negotiations, such as in the Interim Shortage Guidelines negotiations and the Colorado River Water Supply and Demand Study

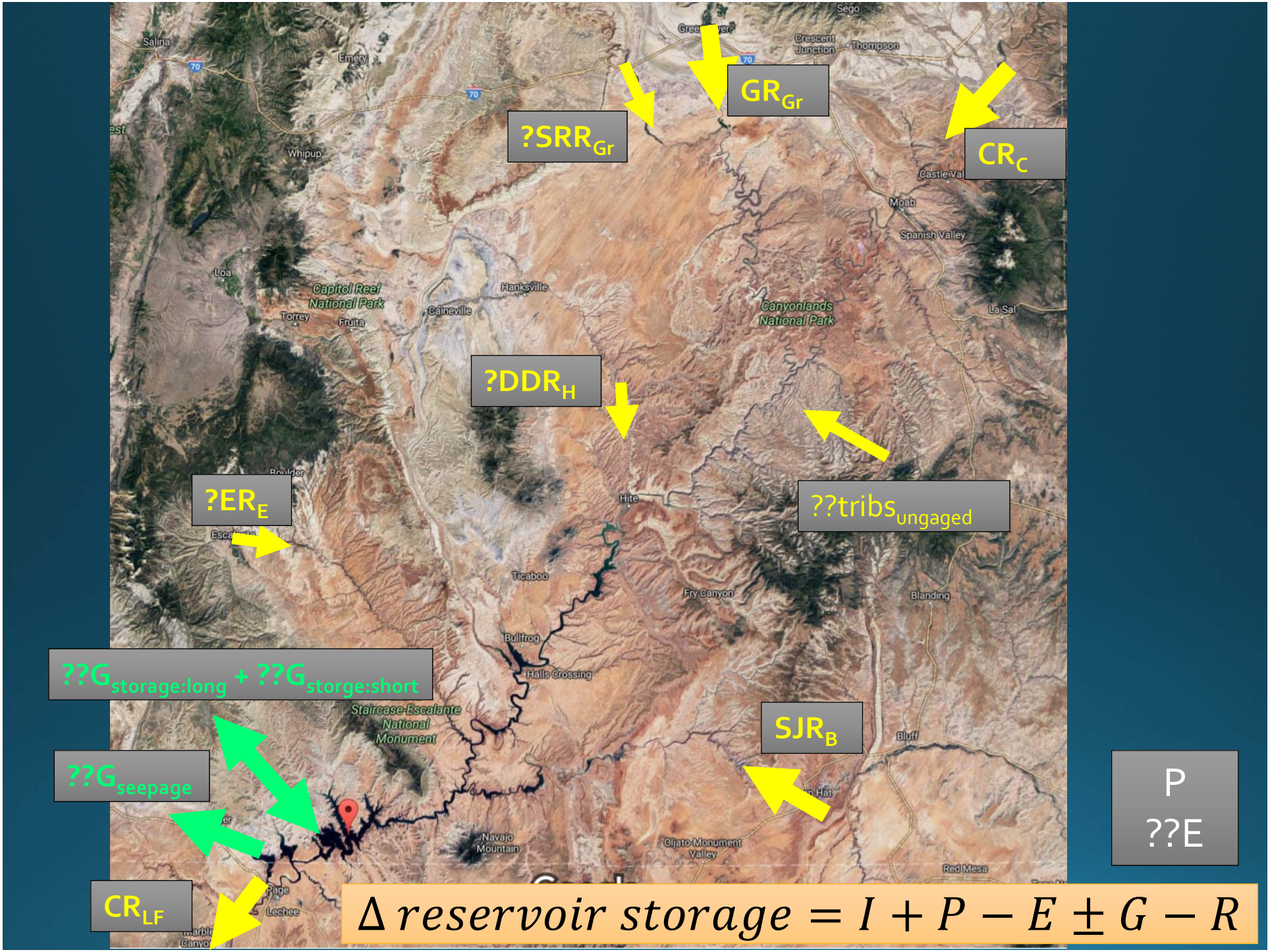
Myers' (2013) estimate of seepage losses

1963 – 2009
Cumulative ground-water storage
9,600,000 – 15,000,000 af/yr

210,000 - 330,000 af/yr



Myers, 2013


GR$_{Gr}$
?SRR$_{Gr}$
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?DDR$_{H}$
?ER$_{E}$
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??G$_{seepage}$
SJR$_{B}$
CR$_{LF}$
P
??E
Salina
Emery
Whipup
Loa
Capitol Reef National Park
Torrey
Fruita
Caineville
Hanksville
Canyonlands National Park
Crescent Junction
Thompson
Sego
Moab
Spanish Valley
La Sal
Hite
Ticaboo
Fry Canyon
Blanding
Bullfrog
Halls Crossing
Staircase-Escalante National Monument
Navajo Mountain
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Red Mesa
Bluff
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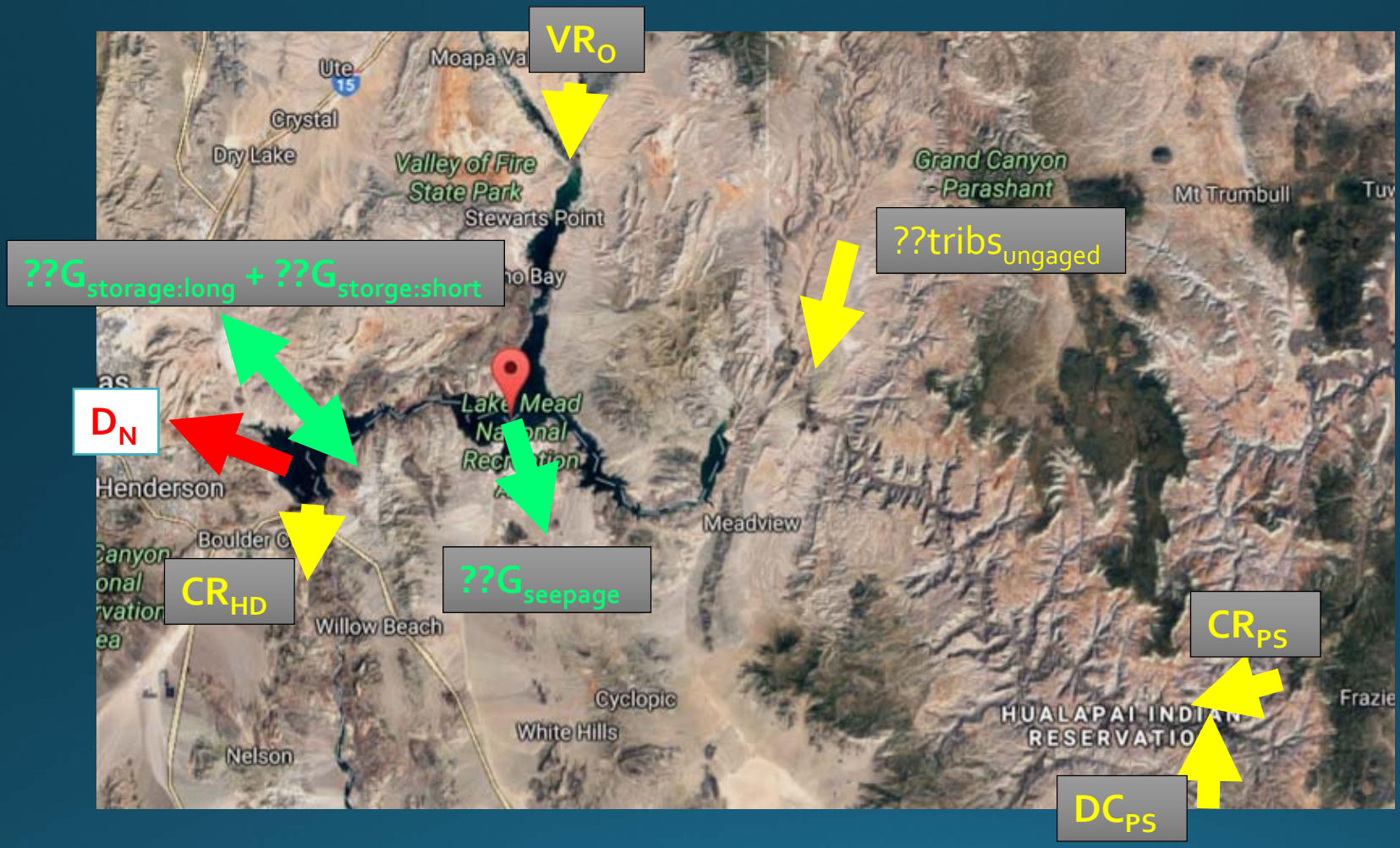
$\Delta\, reservoir\ storage = I + P - E \pm G - R$

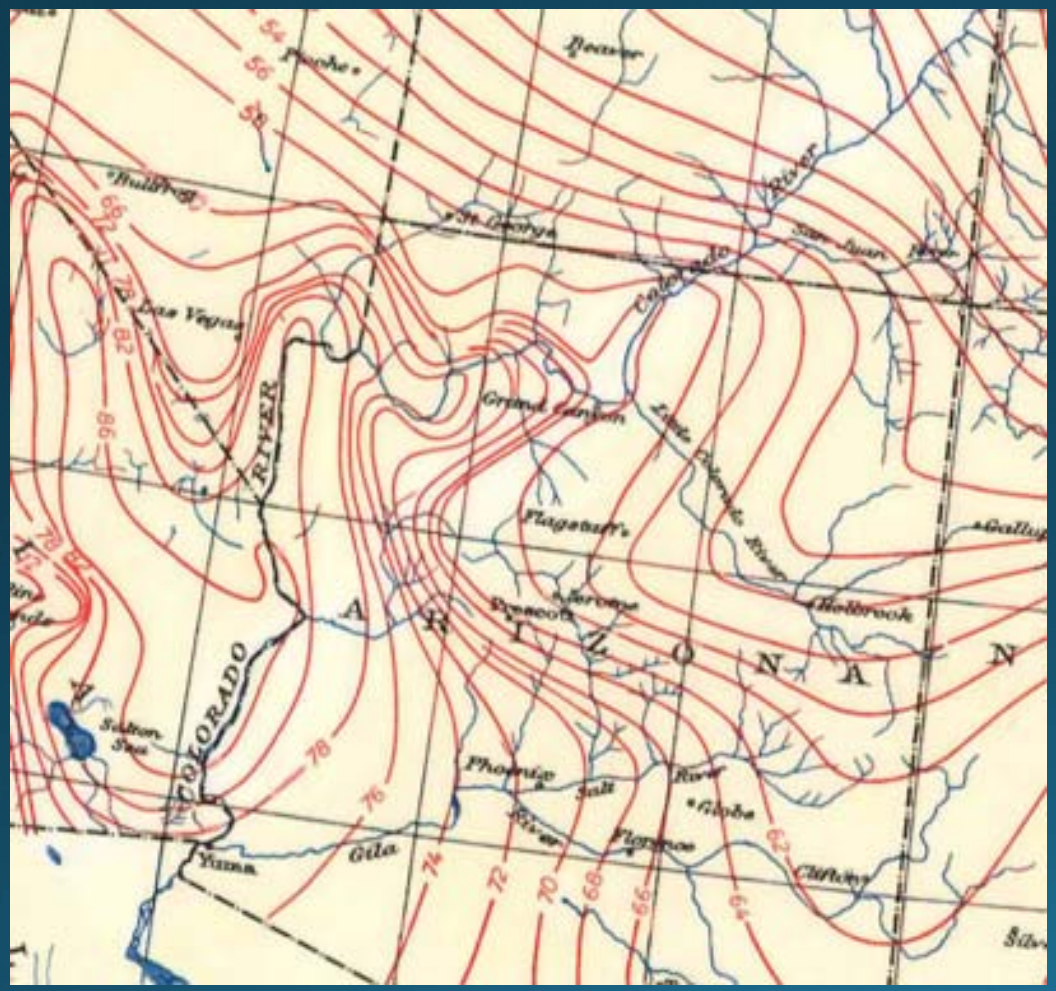


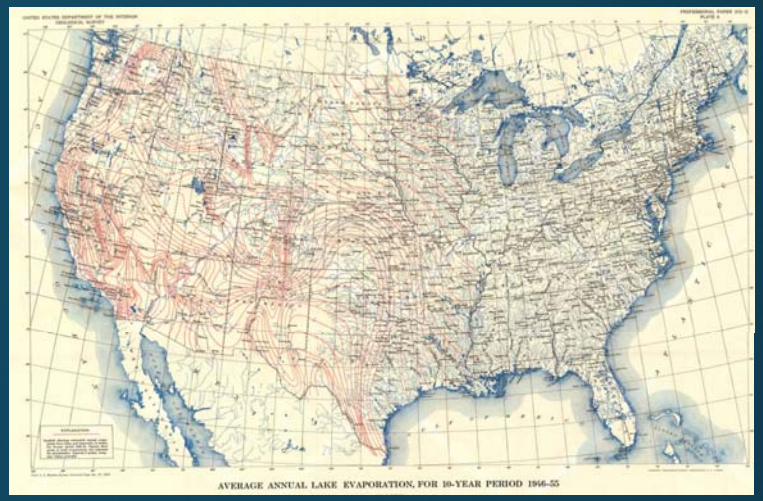
P

??E

$$\Delta\, reservoir\ storage = I + P - E \pm G - R - D$$

Evaporation



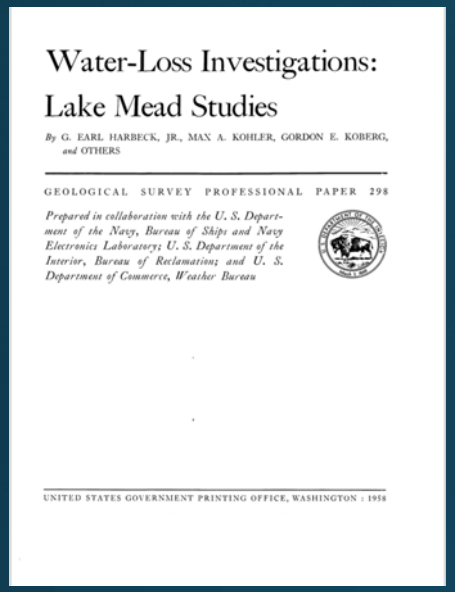


Estimated evaporation rates (1946-1955)

Powell (4.5 ft/yr)
Mead (6.8 ft/yr)

Meyers and Nordenson, 1962, USGS Professional Paper

Previous Studies of Evaporation at Lake Mead



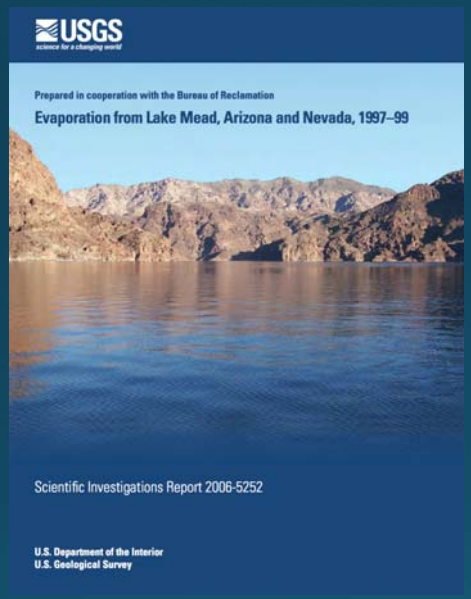
Water-Loss Investigations:
Lake Mead Studies

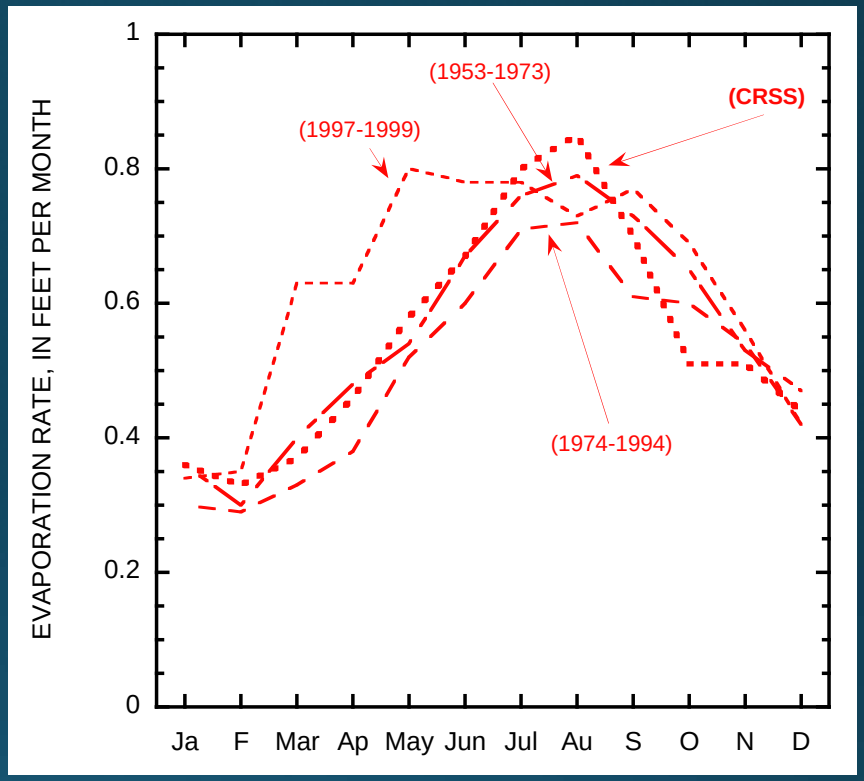
By G. EARL HARBECK, JR., MAX A. KOHLER, GORDON E. KOBERG, and OTHERS

GEOLOGICAL SURVEY PROFESSIONAL PAPER 298

Prepared in collaboration with the U. S. Department of the Navy, Bureau of Ships and Navy Electronics Laboratory; U. S. Department of the Interior, Bureau of Reclamation; and U. S. Department of Commerce, Weather Bureau

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1958





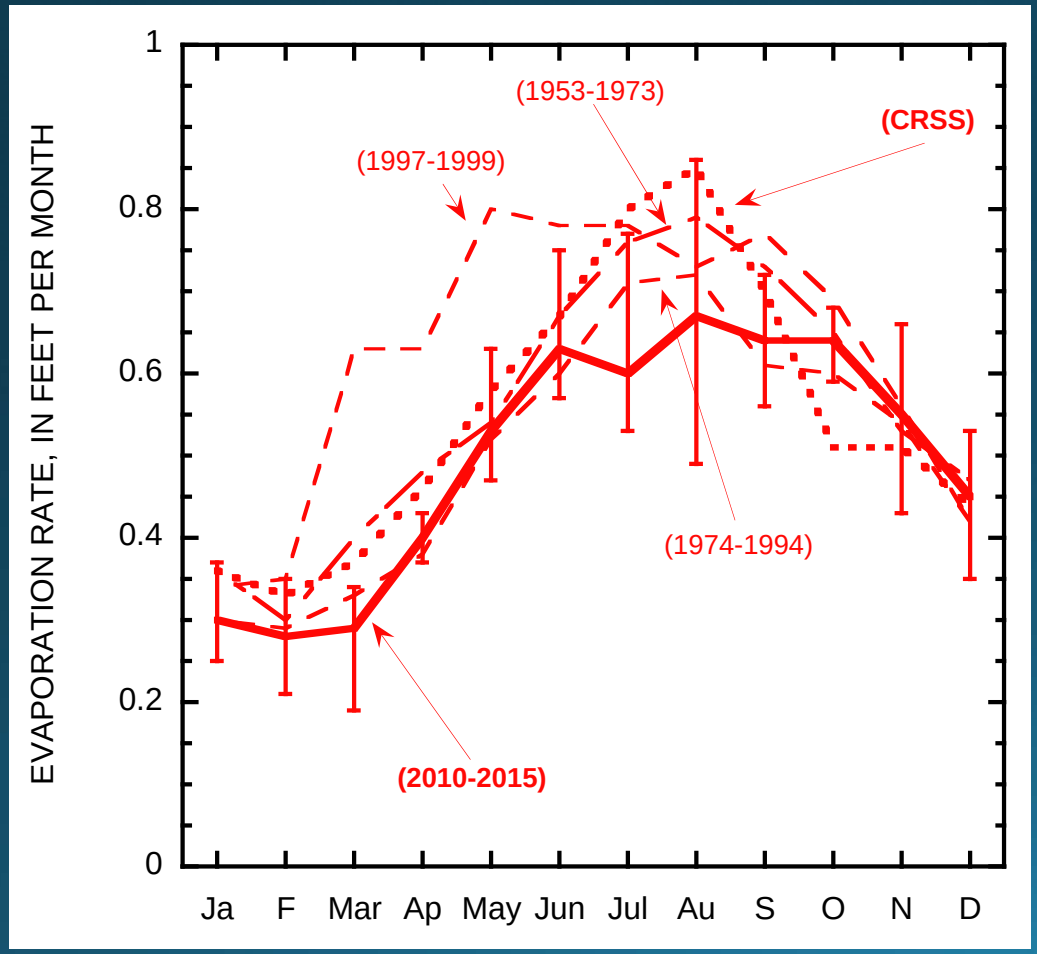
- Water budgets
- Mass transfer
- Energy budget

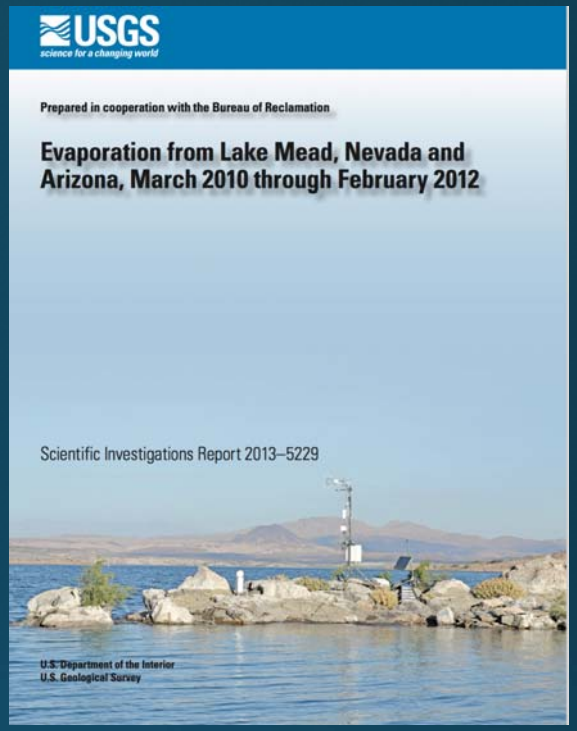
Anderson and Prichard (1951) = 5.3 ft/yr
Harbeck et al (1958) = 7.1 ft/yr (in 1953)
Harbeck et al (1958) = 7.0 ft/yr (average for 1941-1953)
Westenberg et al (2006)* = 6.7 ft/yr (average for 1953-1973); 6.0 ft/yr (average for 1974-1994)
Westenberg et al (2006) = 7.5 ft/yr (average for 1997-1999)

CRSS = 6.6 ft/yr

2010-2015 ; average evaporation rate = 6.0 ft/yr

Mar 2010 – F 2011 = 6.4 ft/yr
Mar 2013 – F 2014 = 5.5 ft/yr





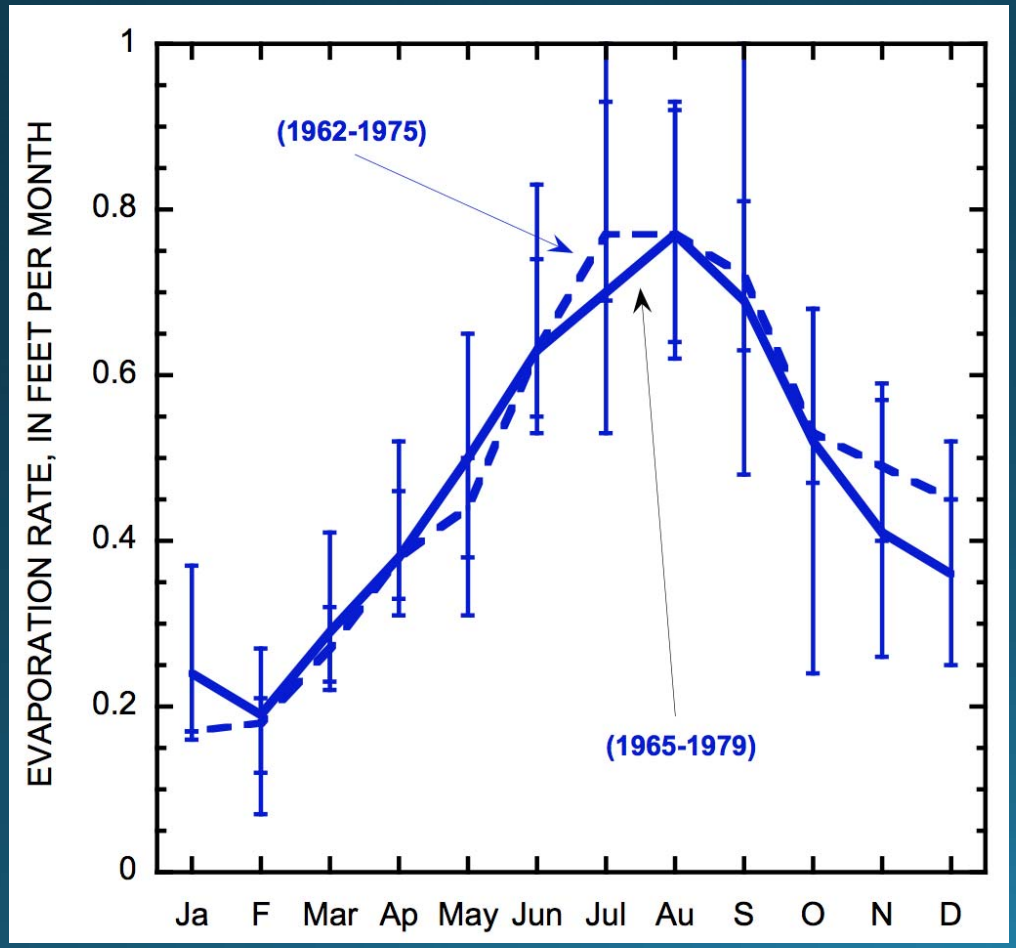
Eddy covariance method

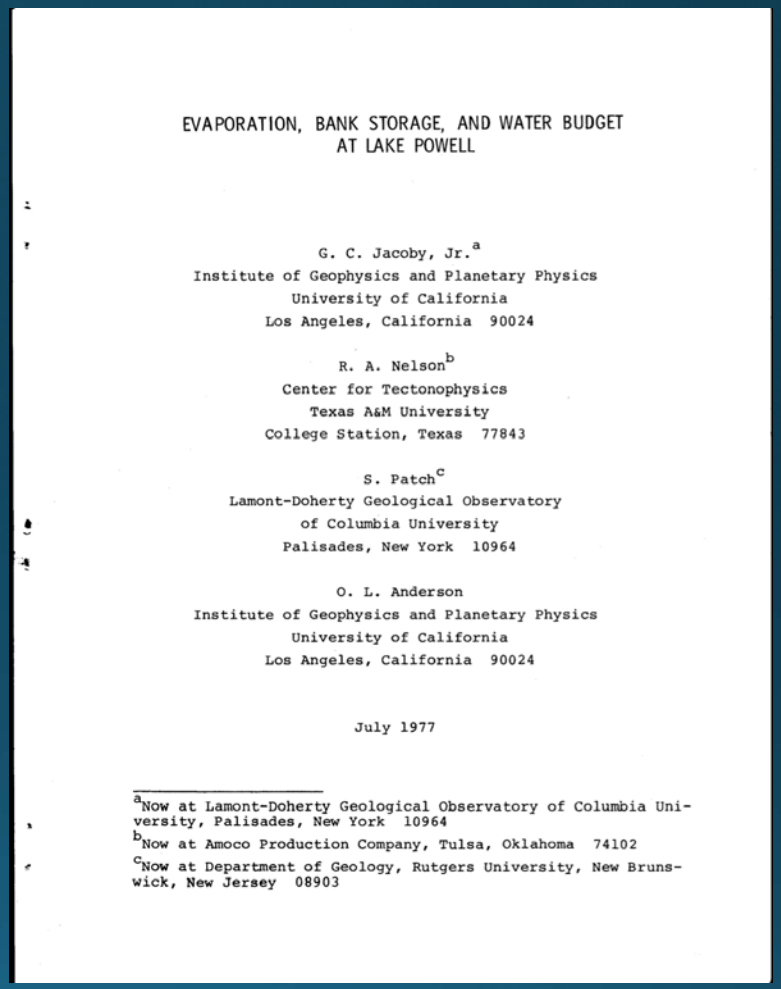
direct measurement of water flux

Moreo and Swancar, 2013; Moreo, 2015

Studies of Evaporation at Lake Powell

Wilson (1962) = 5.5 ft/yr
Jacoby et al (1977) = 5.8 ft/yr (average for 1962-1975)
Reclamation (1986) = 5.7 ft/yr (average for 1965-1979)





EVAPORATION, BANK STORAGE, AND WATER BUDGET AT LAKE POWELL

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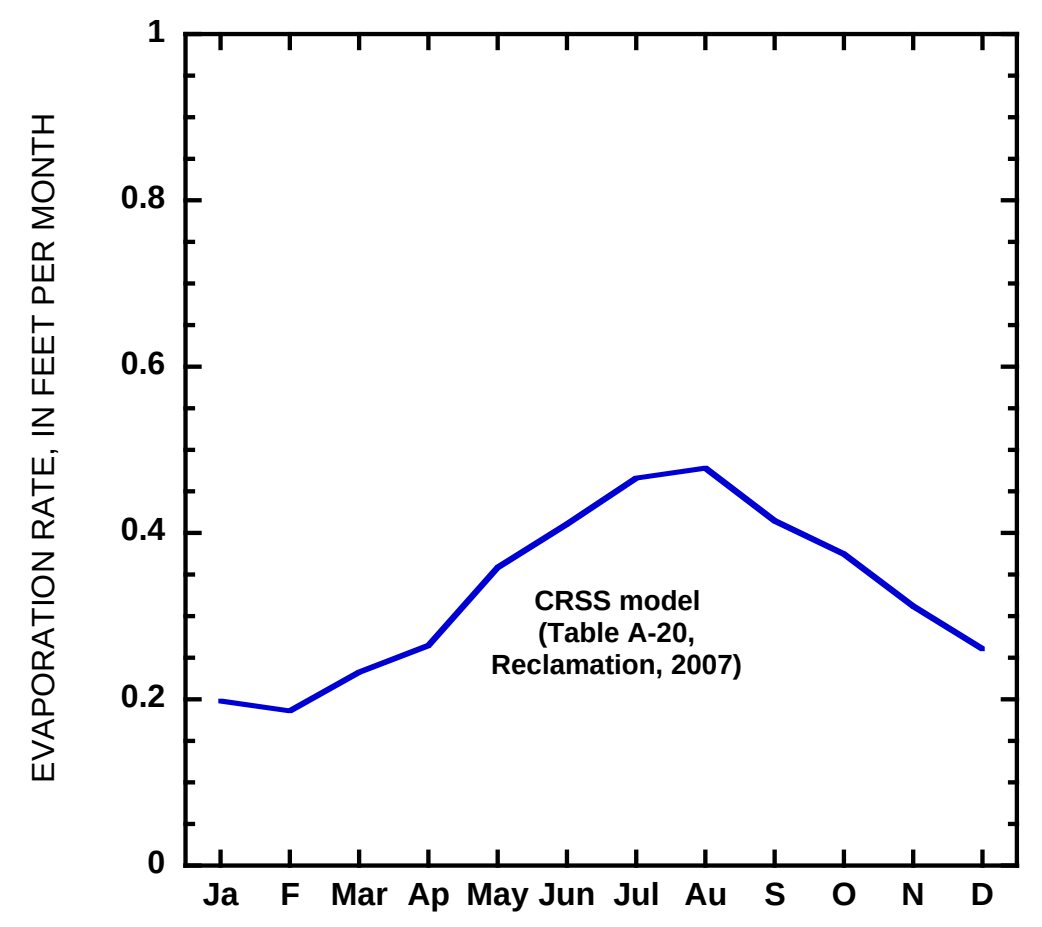
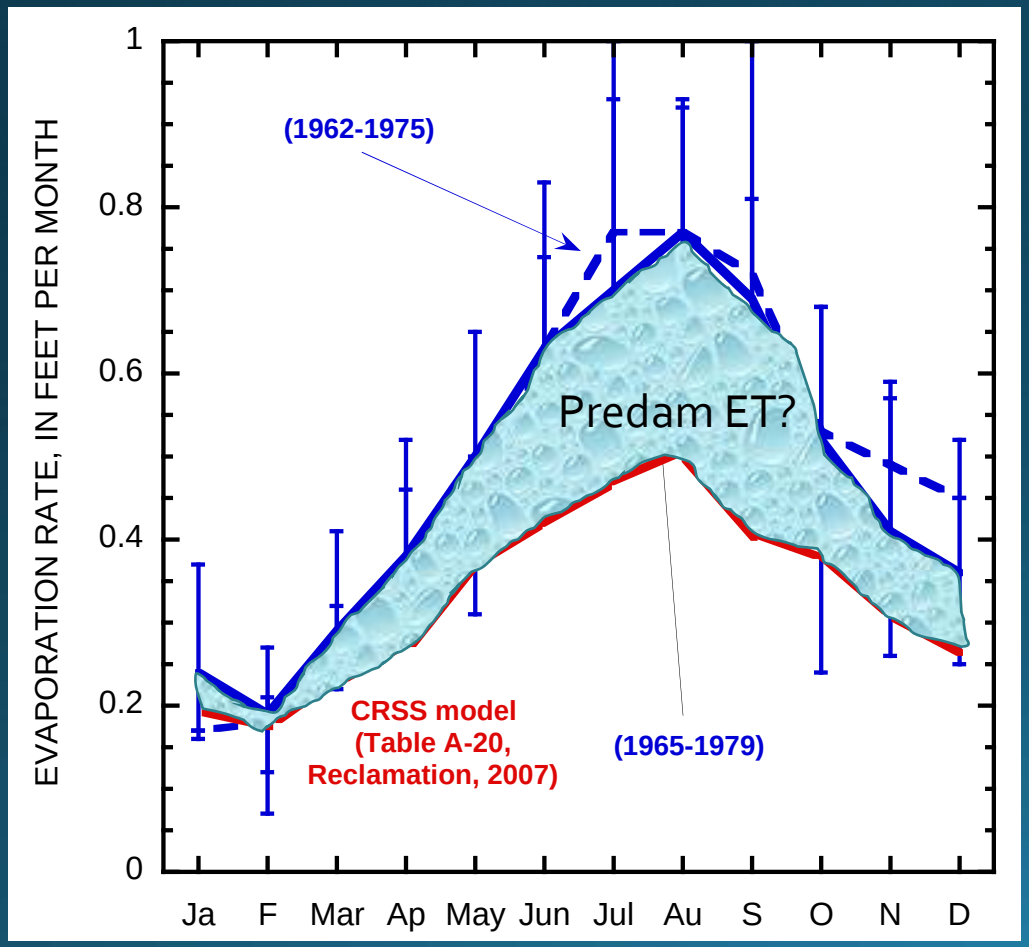
Evaporation at Lake Powell reported in Interim Shortage Guidelines EIS and at GCD data website



Total annual evaporation used in CRSS = 4.0 ft/yr

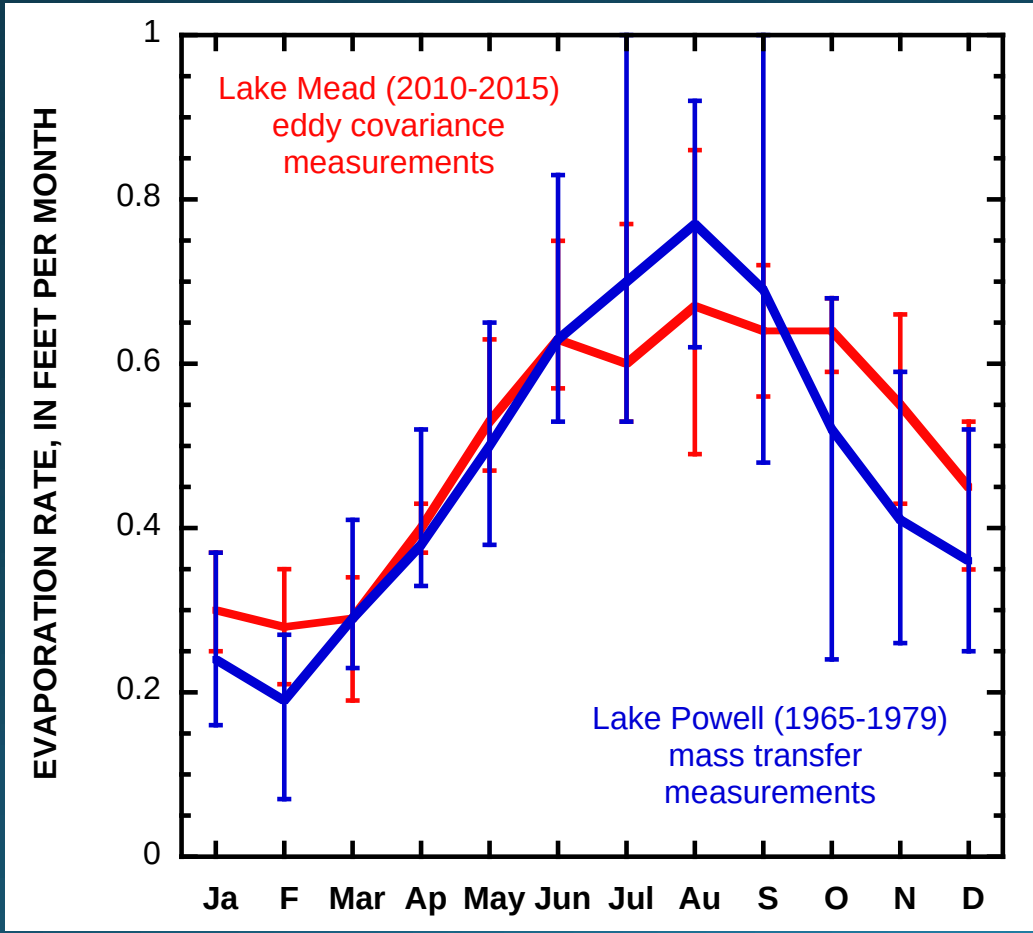
Evaporation at Lake Powell is often reported as "net," which is total evaporation minus evapotranspiration that occurred before Glen Canyon Dam was constructed



Total annual evaporation used in CRSS = 4.0 ft/yr

This value is the net evaporation and does not include the estimated pre-dam evapotranspiration from the Colorado River and its floodplain

Most recent ***total*** evaporation measurements at each reservoir



Long-term average annual precipitation is approximately the same at the two reservoirs

Average annual precipitation near Lake Powell

0.4 ft/yr @ Hite Marina (1968-1978)

0.5 ft/yr @ Bullfrog Basin (1967-2016);Hite (1900-1962);
Page (1957-2005); Wahweap (1961-2012)

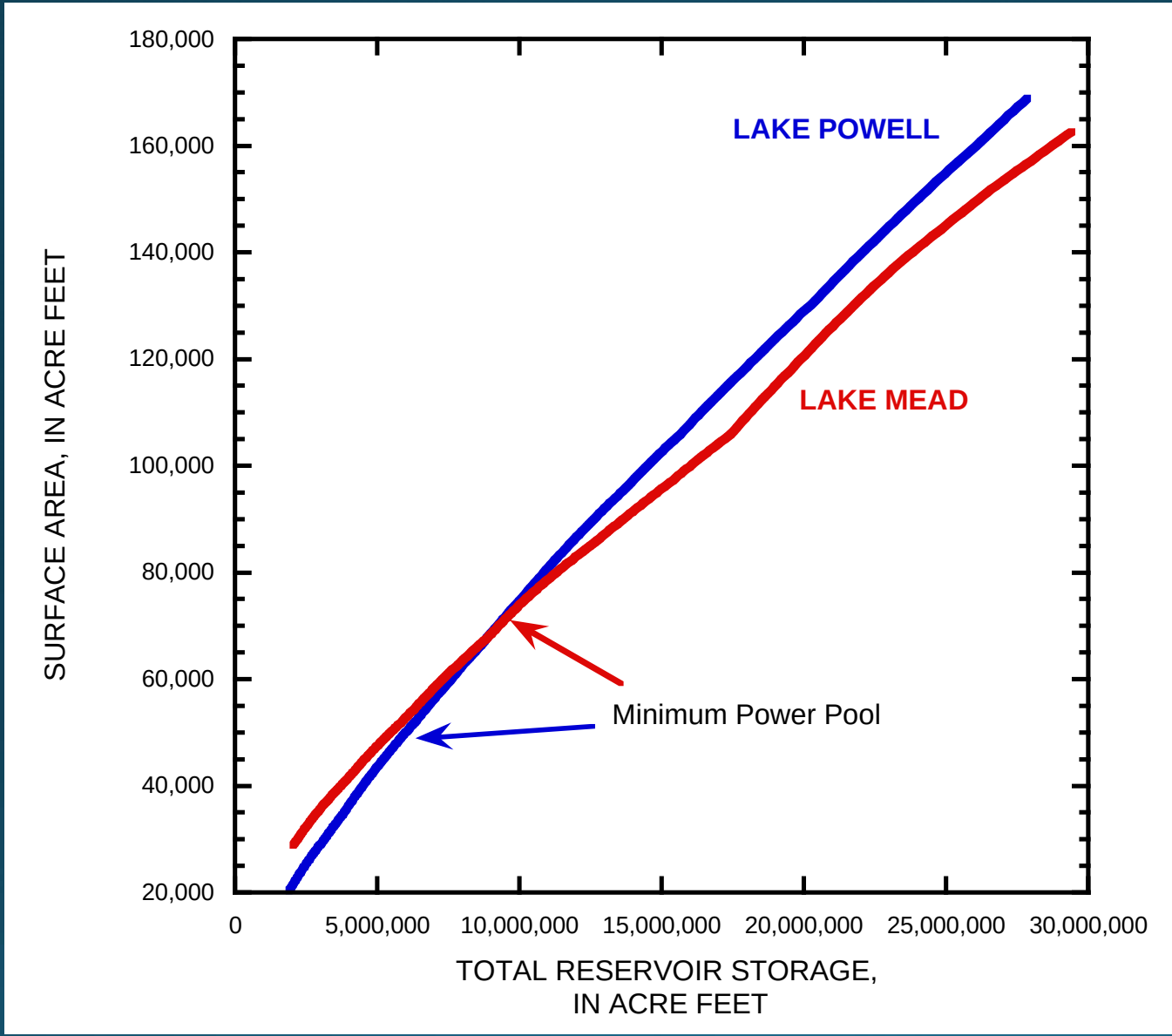
0.6 ft/yr @ Hite Ranger Station (1978-2015)

Average annual precipitation near Lake Mead

0.5 ft/yr @ Boulder City (1931-2005); Callville Bay (1989-2011); Echo Bay (1989-2011); Temple Bar (1987-2009); Willow Beach (1967-2008)

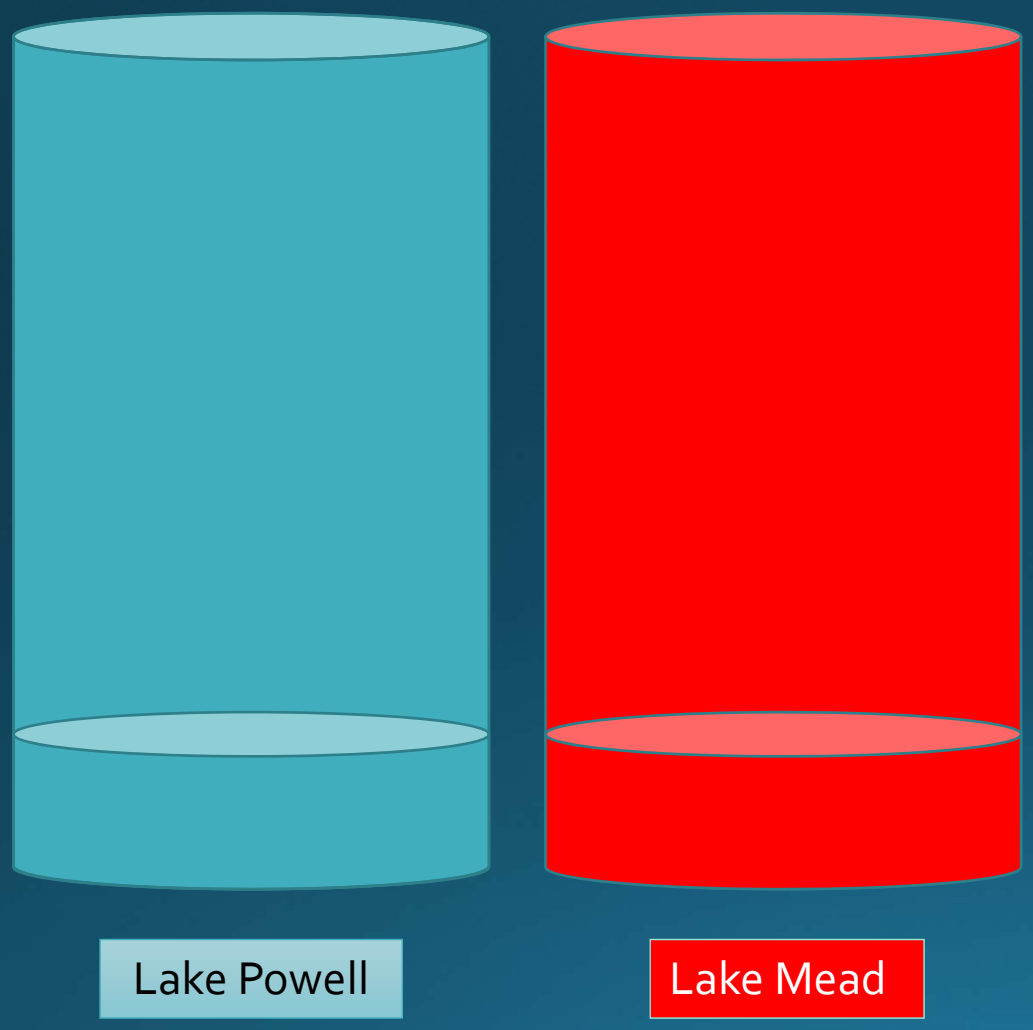
0.9 ft/yr @Pearce Ferry (1963-1984)

Data source: Western Regional Climate Center website

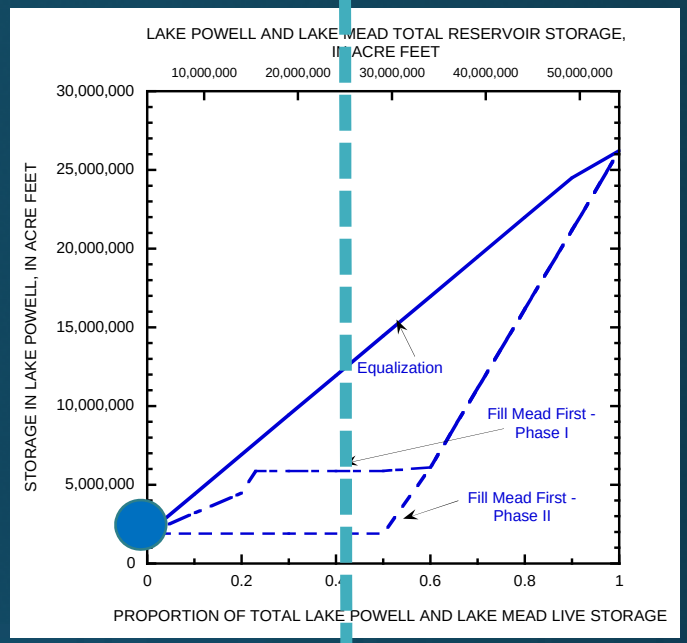


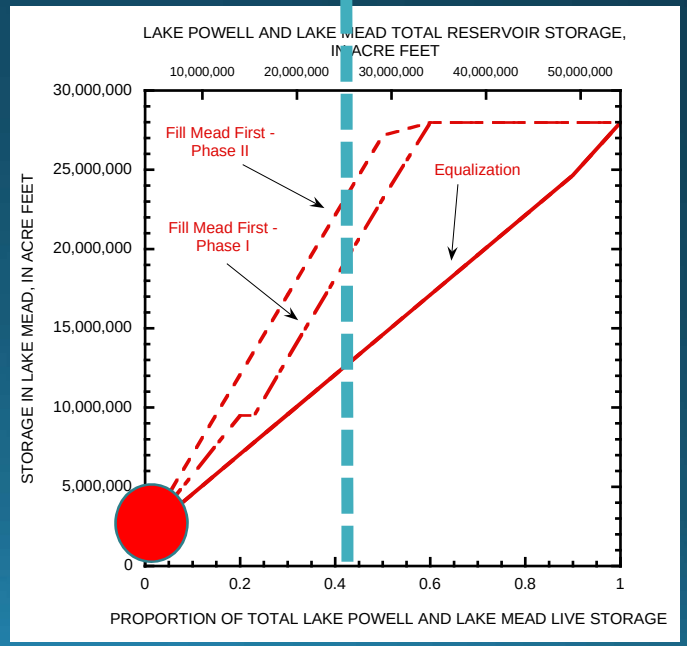
Surface area of Lake Powell > Lake Mead when reservoir storage is more than 10,000,000 af,

Assumptions of how storage is allocated between reservoirs -- equalization

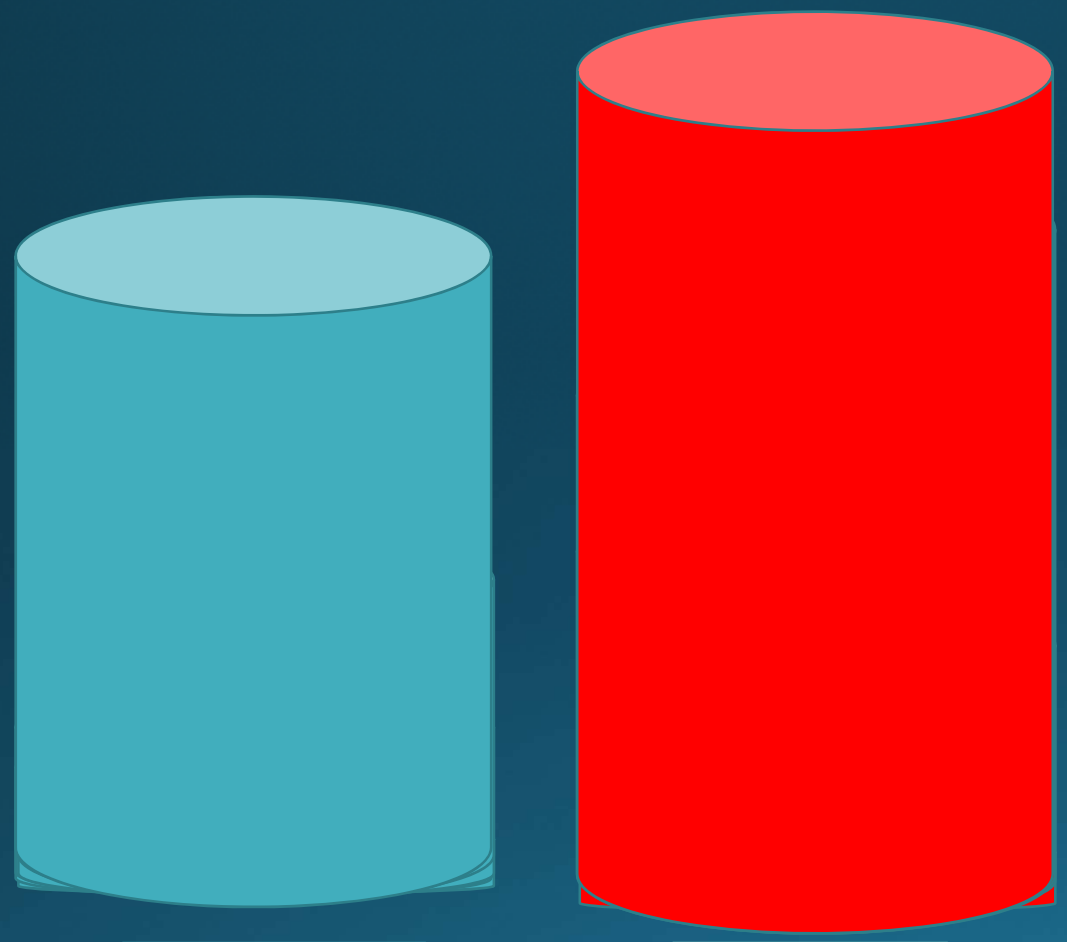


February 2017





Assumptions of how storage is allocated between reservoirs – FMF Phase I



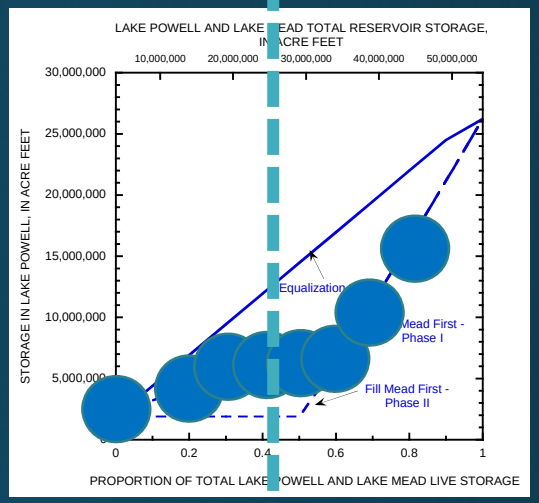
Lake Powell

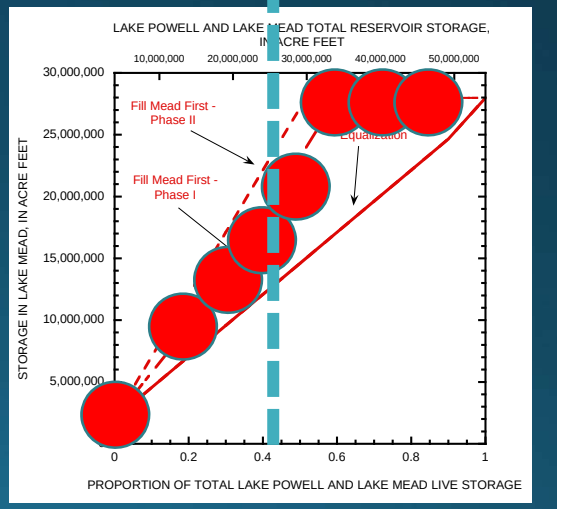
Lowest volume since filling April 2005 = 8.0 maf (33% of active capacity)

Lake Mead

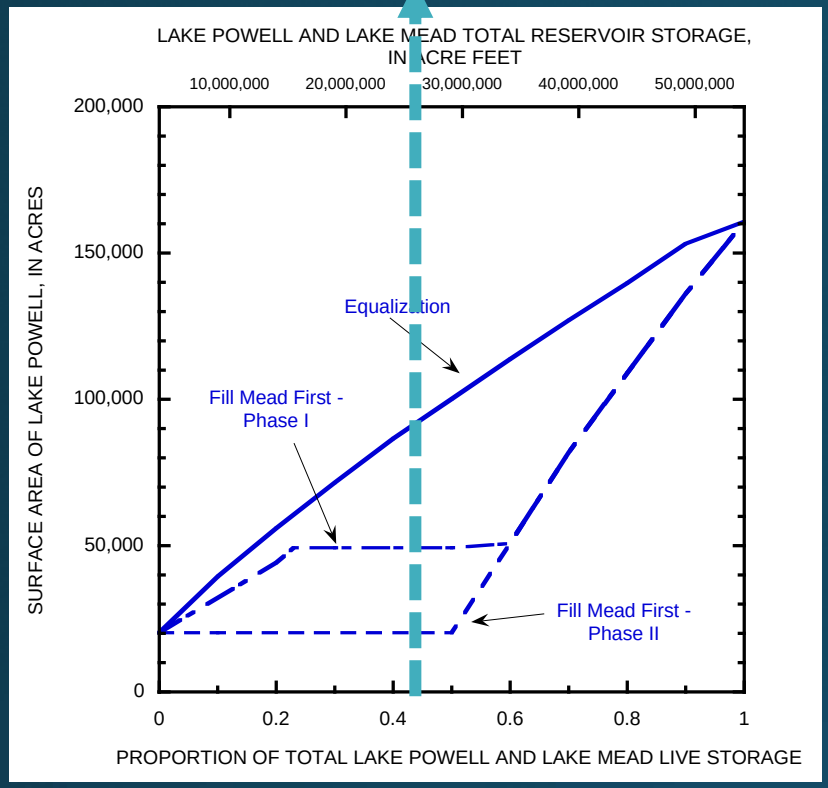
Lowest volume since filling July 2016 = 9.3 maf (36% of active capacity)

February 2017

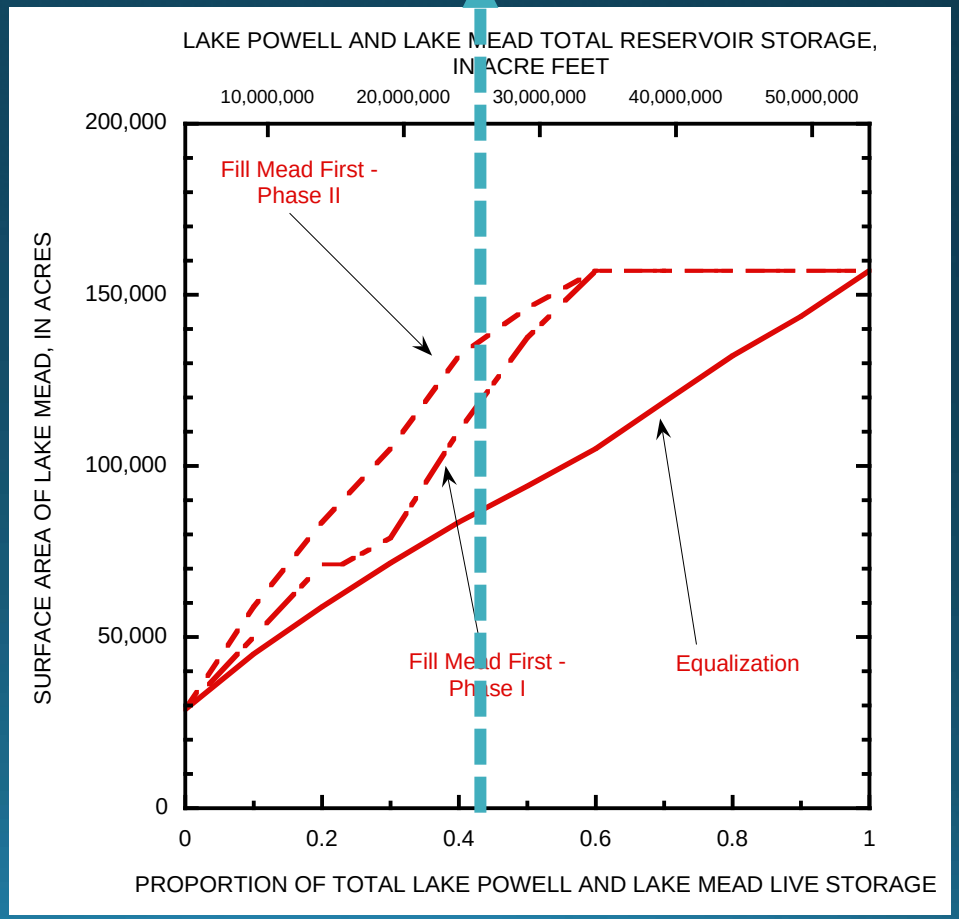




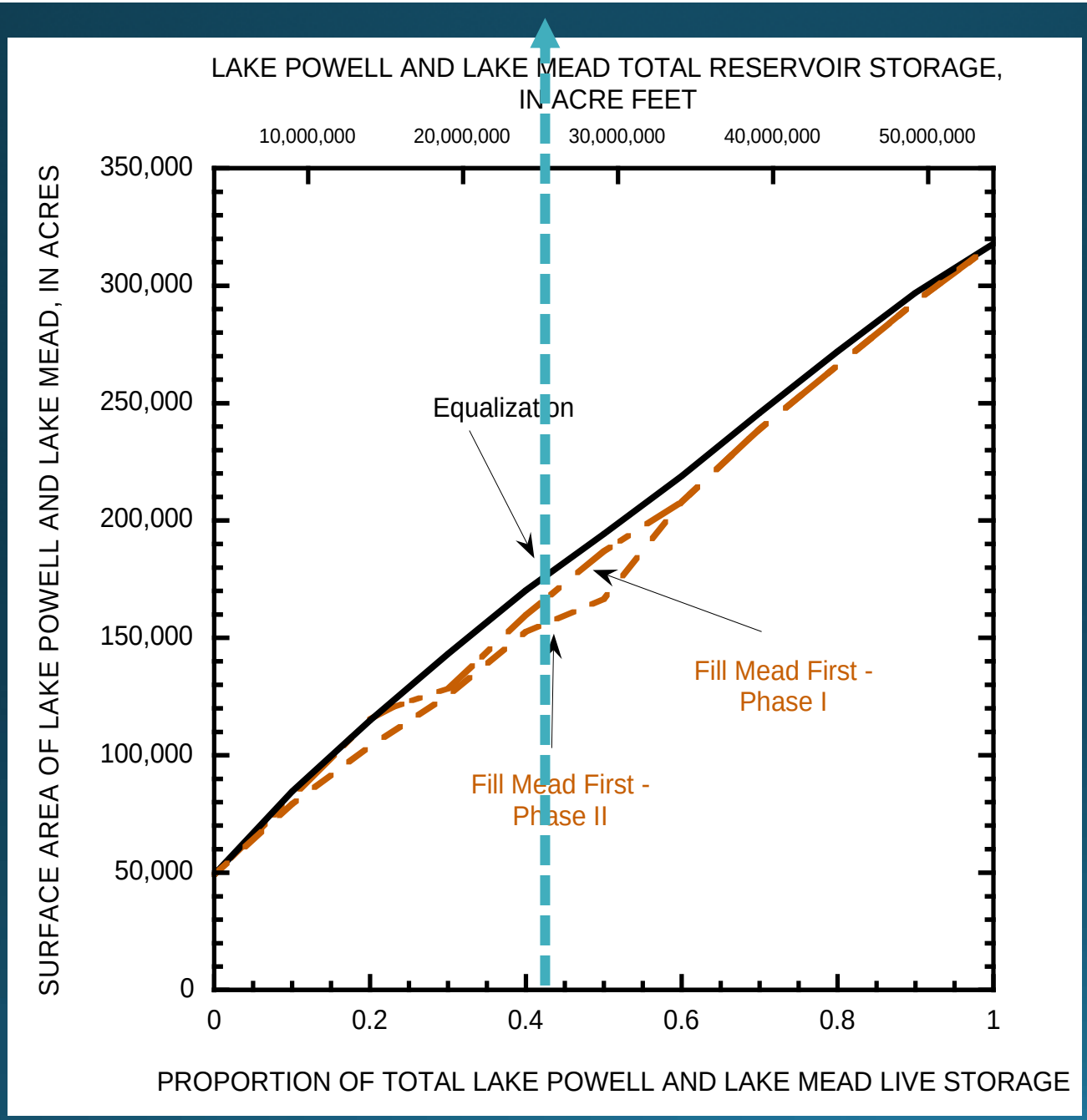
Surface area of each reservoir under different management scenarios



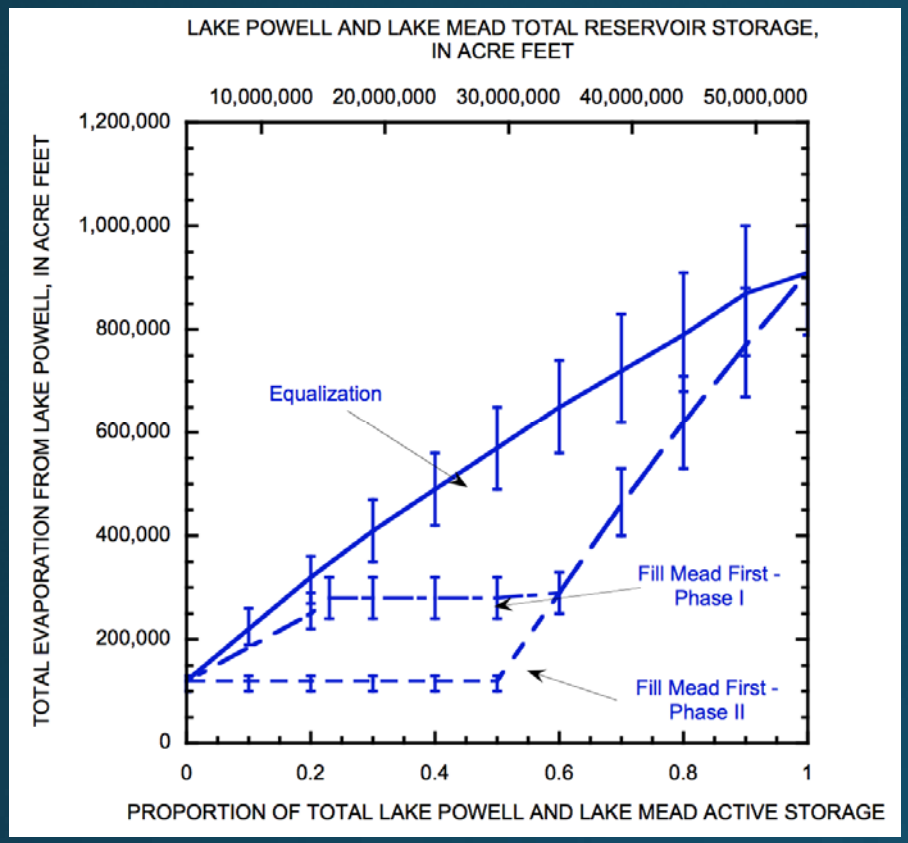
Lake Powell



Lake Mead



Implementation of FMF would reduce the total surface area of reservoir storage



Evaporation from Lake Powell is 420,000 – 560,000 af/yr when active storage is ~10,100,000 af

Evaporation from Lake Powell is 560,000 – 740,000 af/yr when active storage is ~15,100,000 af

Evaporation from Lake Powell is 670,000 – 910,000 af/yr when active storage is ~20,100,000 af

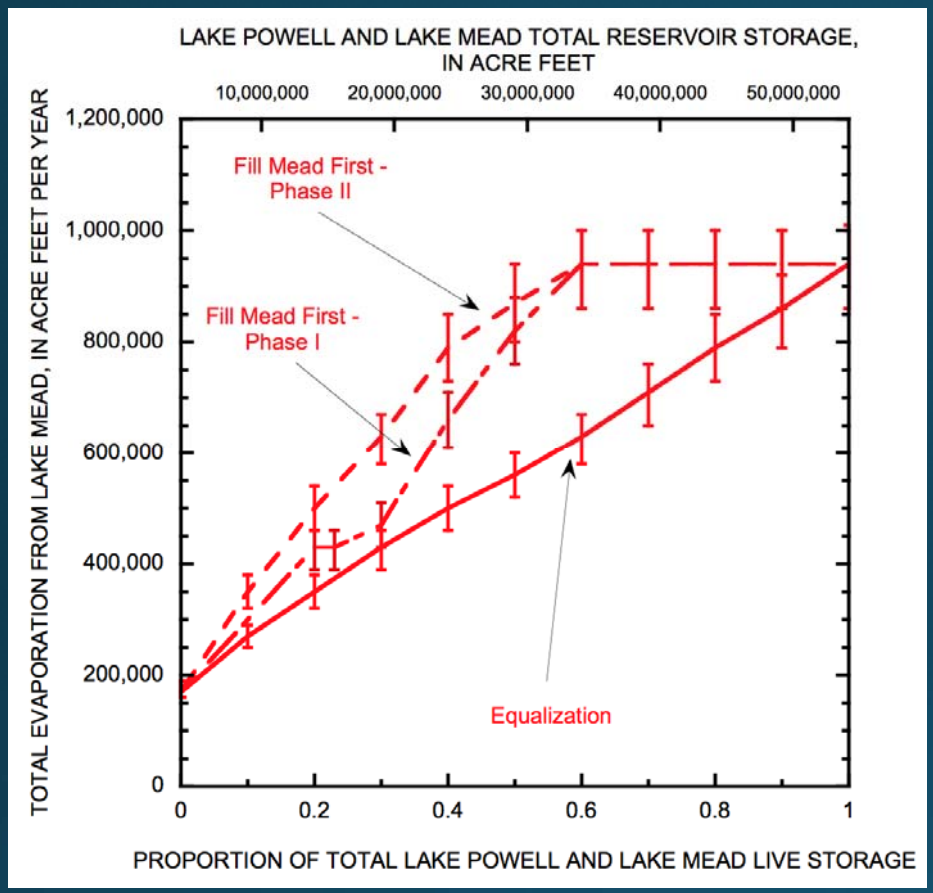
Evaporation at Lake Powell under Equalization

LP active storage (XX% of LP/LM total active storage) = evaporation (uncertainty)

5.0 maf$_P$ (20%) = 0.32 maf/yr (± 0.045 maf/yr)
10.1 maf$_P$ (40%) = 0.49 maf/yr (±0.070 maf/yr)
15.1 maf$_P$ (60%) = 0.65 maf/yr (±0.090 maf/yr)
20.1 maf$_P$ (80%) = 0.79 maf/yr (±0.12 maf/yr)
24.3 maf (100%) = 0.91 maf/yr (±0.11 maf/yr)

Under FMF Phase I

2.6 maf$_P$ = 0.25 maf/yr ((± 0.035 maf/yr)
4.0 maf$_P$ = 0.28 maf/yr (± 0.040 maf/yr)
4.2 maf$_P$ = 0.29 maf/yr (± 0.040 maf/yr)
14.3 maf$_P$ = 0.62 maf/yr (± 0.090 maf/yr)
24.3 maf$_P$ = 0.91 maf/yr (± 0.110 maf/yr



Evaporation from Lake Mead is 460,000 – 540,000 af/yr when active storage is ~10,100,000 af

Evaporation from Lake Mead is 590,000 – 680,000 af/yr when active storage is ~15,100,000 af

Evaporation from Lake Mead is 730,000 – 850,000 af/yr when active storage is ~20,100,000 af

Evaporation at Lake Mead under Equalization

LP active storage (XX% of LP/LM total active storage) = evaporation (uncertainty)

5.0 maf_M (20%) = 0.35 maf/yr (± 0.030 maf/yr)
10.1 maf_M (40%) = 0.50 maf/yr (±0.040 maf/yr)
15.1 maf_M (60%) = 0.63 maf/yr (±0.045 maf/yr)
20.1 maf_M (80%) = 0.79 maf/yr (±0.060 maf/yr)
25.9 maf_M (100%) = 0.94 maf/yr (±0.075 maf/yr)

Under FMF Phase I

7.5 maf_M = 0.43 maf/yr ((± 0.035 maf/yr)
16.1 maf_M = 0.66 maf/yr (± 0.050 maf/yr)
25.9 maf_M = 0.94 maf/yr (± 0.070 maf/yr)
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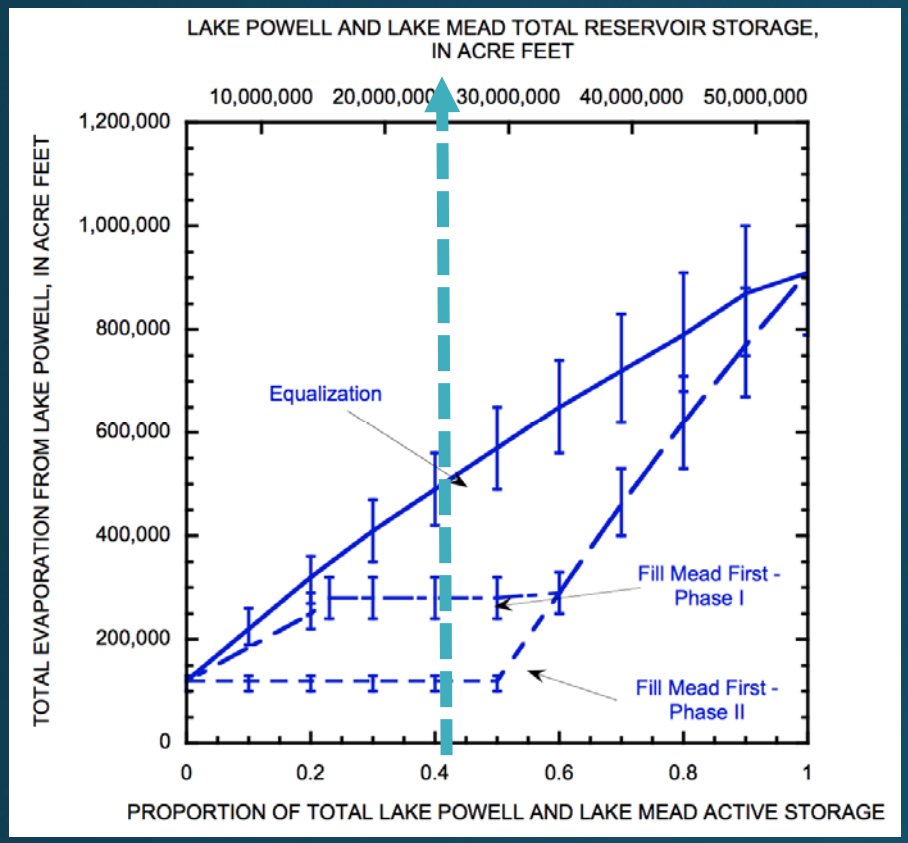
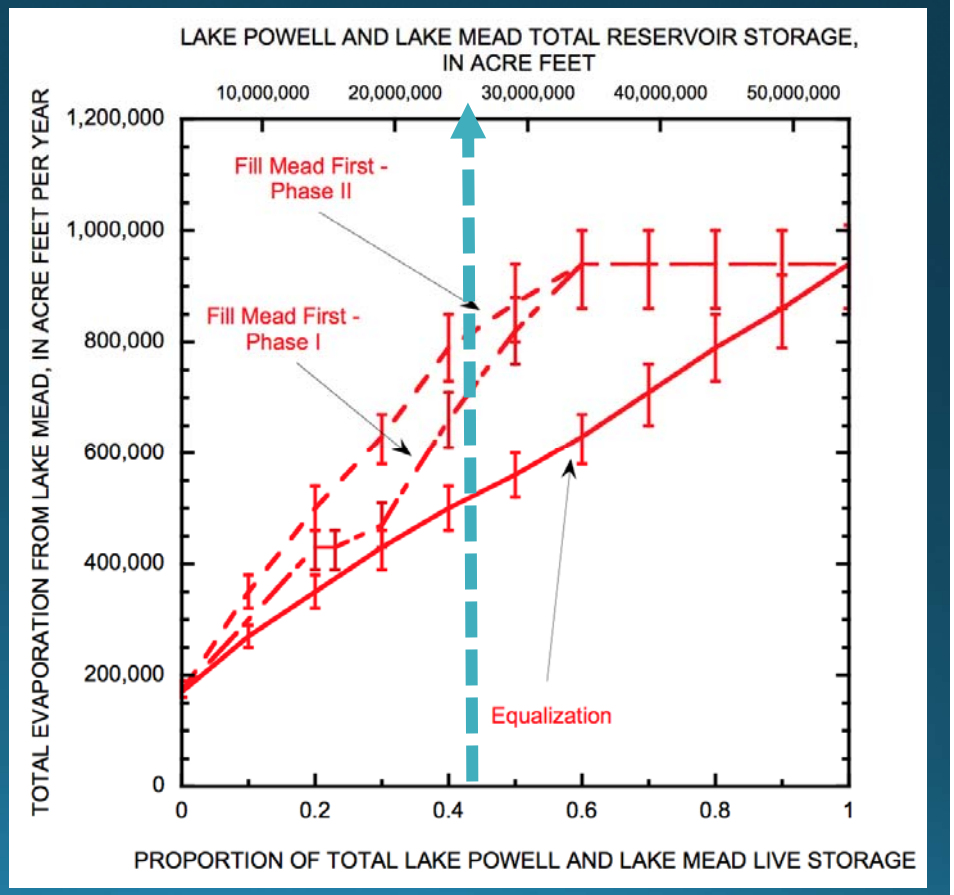


Lake Powell

When total active storage is 40% capacity:

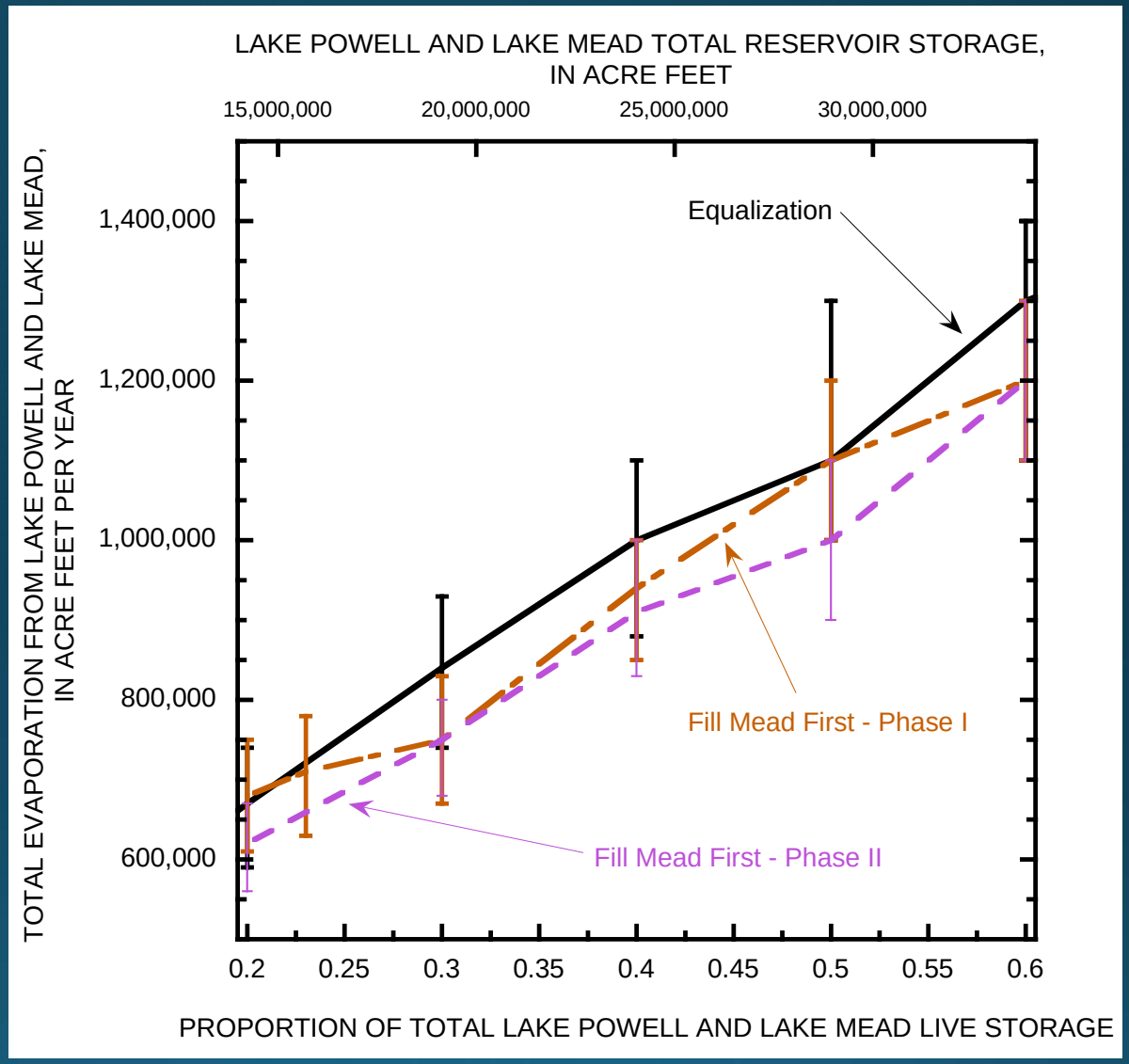
Equalization:
Powell evaporation = 560,000-740,000 af/yr
Mead evaporation = 590,000 – 680,000 af/yr

FMF (Phase I):
Powell evaporation = 250,000-330,000 af/yr
Mead evaporation = 870,000 – 1,100,000 af/yr



Lake Mead

Evaporation losses ***might*** be reduced if water is preferentially stored in Lake Mead rather than distributing the water in both reservoirs, but uncertainty is very high

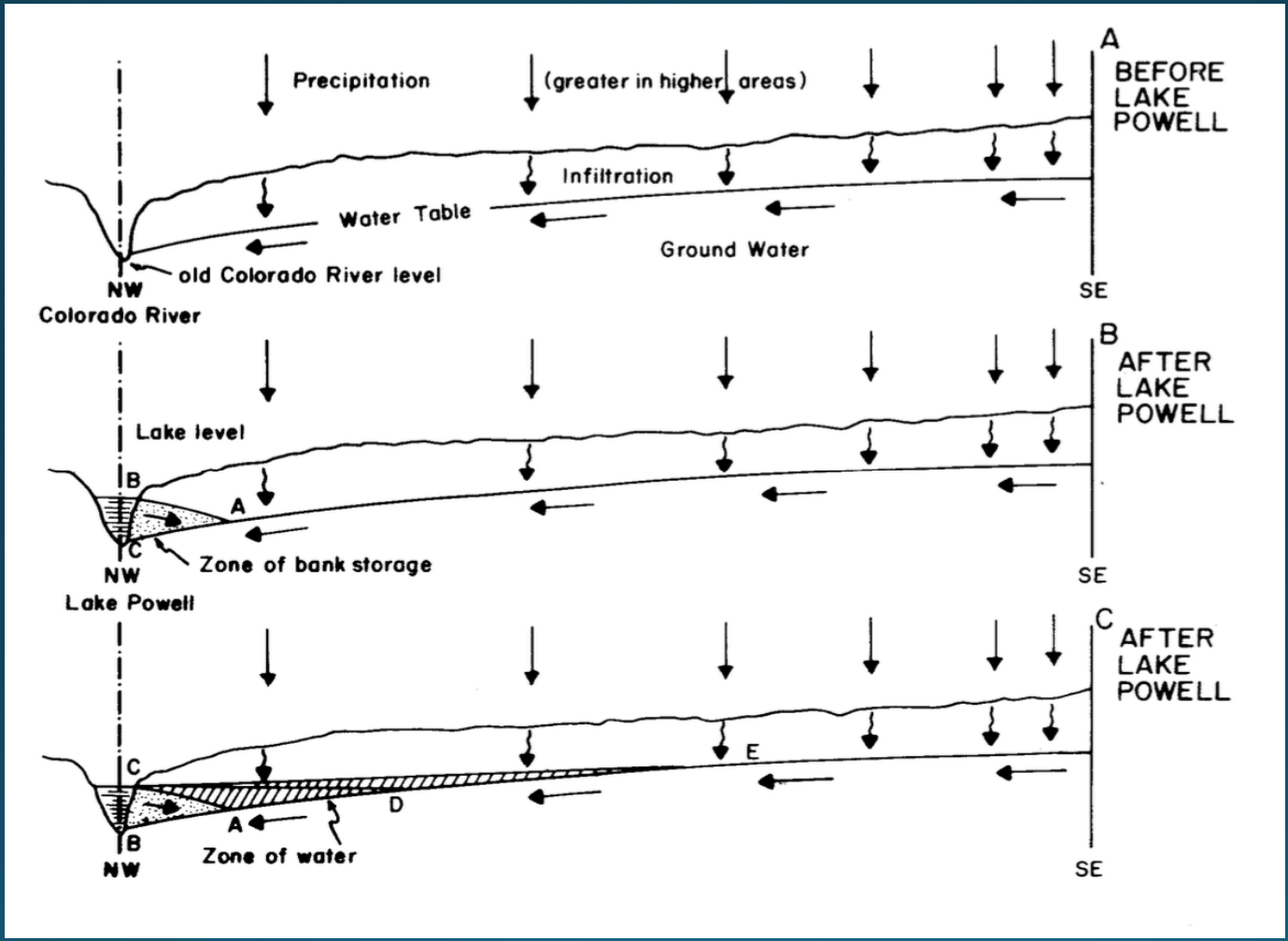


Combined evaporation from both reservoirs. Error bars indicate measured natural range of variability

Conclusions

- Under FMF, reduced storage and reduced evaporation in Lake Powell is approximately matched by increased evaporation from Lake Mead.
- Under Phase I or Phase II of FMF, it cannot be demonstrated that the total evaporation from the two reservoirs would be significantly different from the estimated losses under the equalization rule.
- The uncertainty in these estimates is large.
- State-of-the-science measurements of evaporation are made at Lake Mead; a similar measurement program is not in place at Lake Powell.

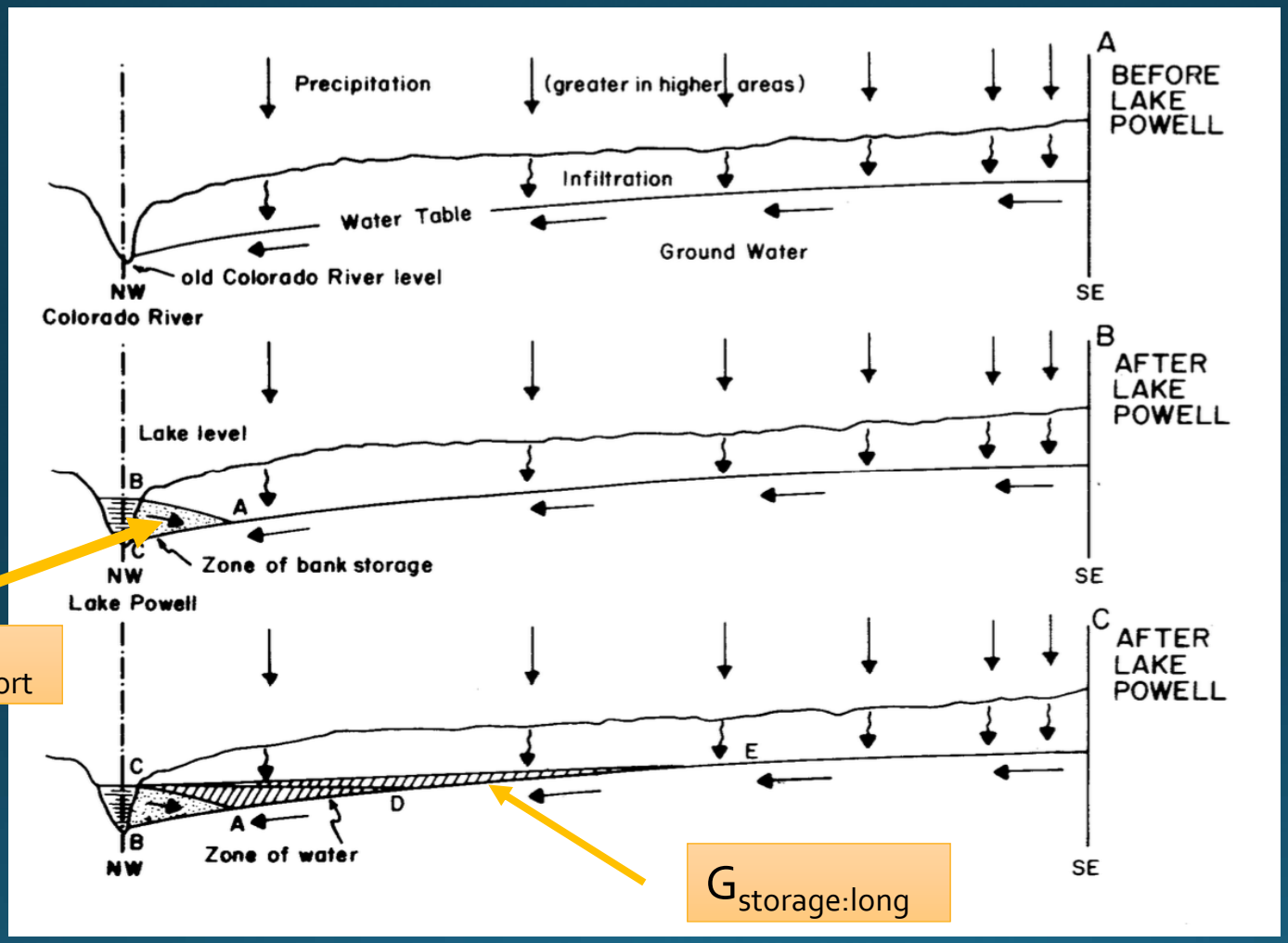
Movement of Reservoir Water into Surrounding Ground Water



Jacoby et al., 1977

Movement of reservoir water into surrounding ground-water system is inevitable

Long-term and short-term ground-water storage was anticipated at Lake Powell; seepage was not anticipated



$G_{storage:short}$

$G_{storage:long}$

Jacoby et al., 1977

??? $G_{seepage}$

$$losses = G_{storage:long} + G_{seepage} + E$$

STATE OF UTAH
DEPARTMENT OF NATURAL RESOURCES

Technical Publication No. 84

GROUND-WATER CONDITIONS IN THE LAKE POWELL AREA, UTAH

by

Paul J. Blanchard
Hydrologist, U.S. Geological Survey

Prepared by
the United States Geological Survey
in cooperation with
The Utah Department of Natural Resources
Division of Water Rights

1986

SIMULATION ANALYSIS OF WATER-LEVEL CHANGES IN THE NAVAJO SANDSTONE DUE TO CHANGES IN THE ALTITUDE OF LAKE POWELL NEAR WAHWEAP BAY, UTAH AND ARIZONA

By Blakemore E. Thomas

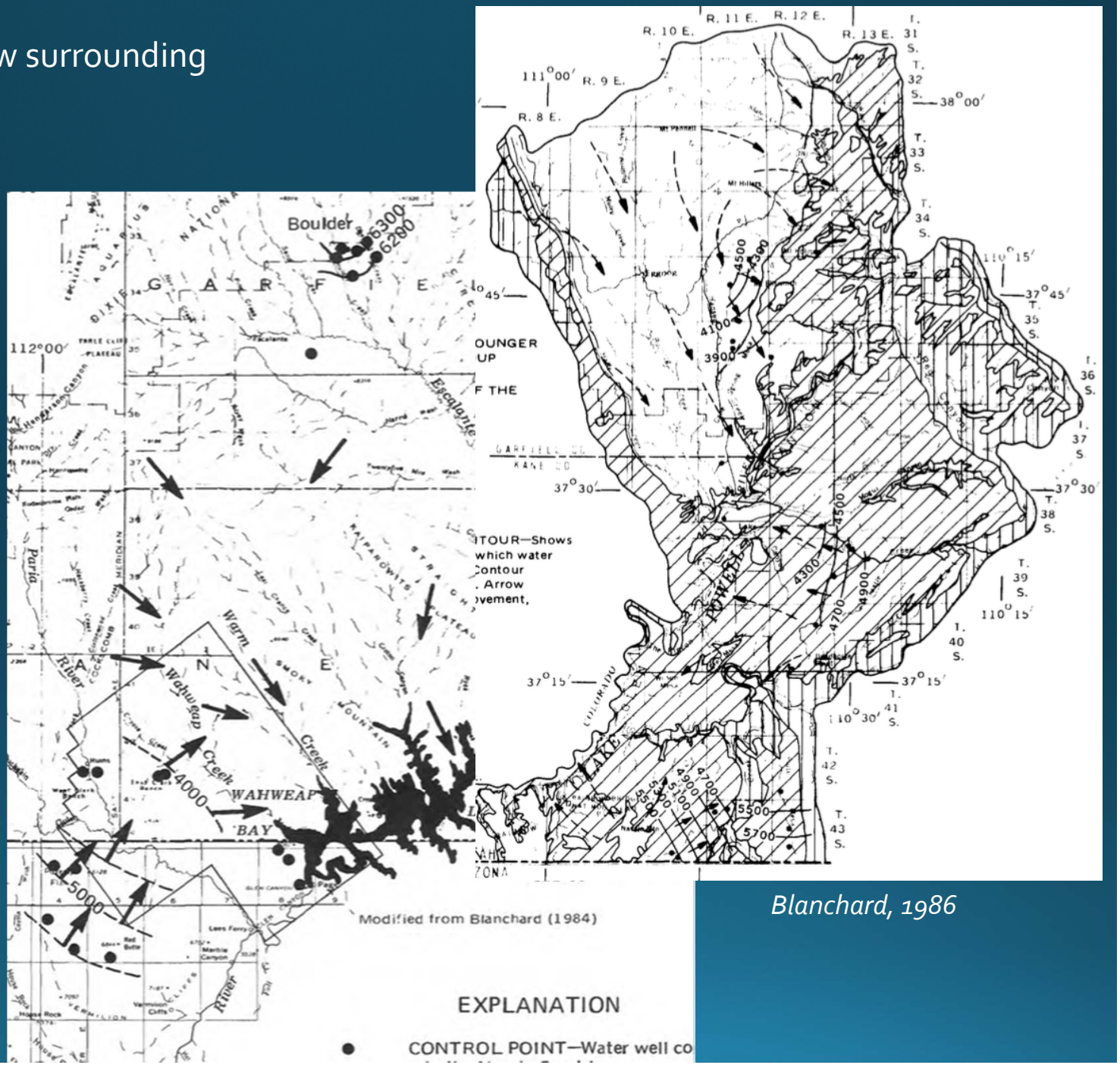
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4207

Salt Lake City, Utah

1986

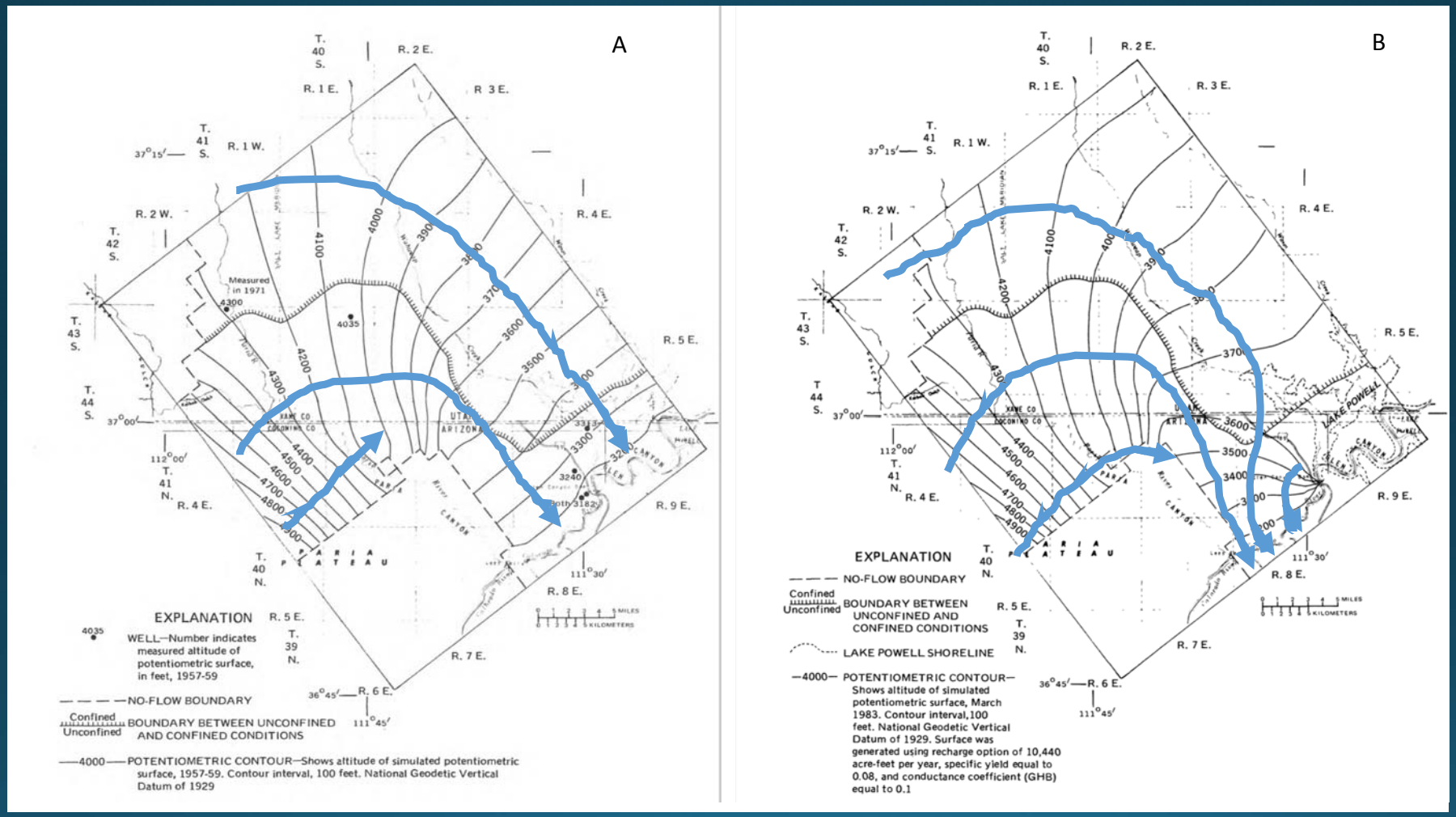
Ground-water flow surrounding Lake Powell



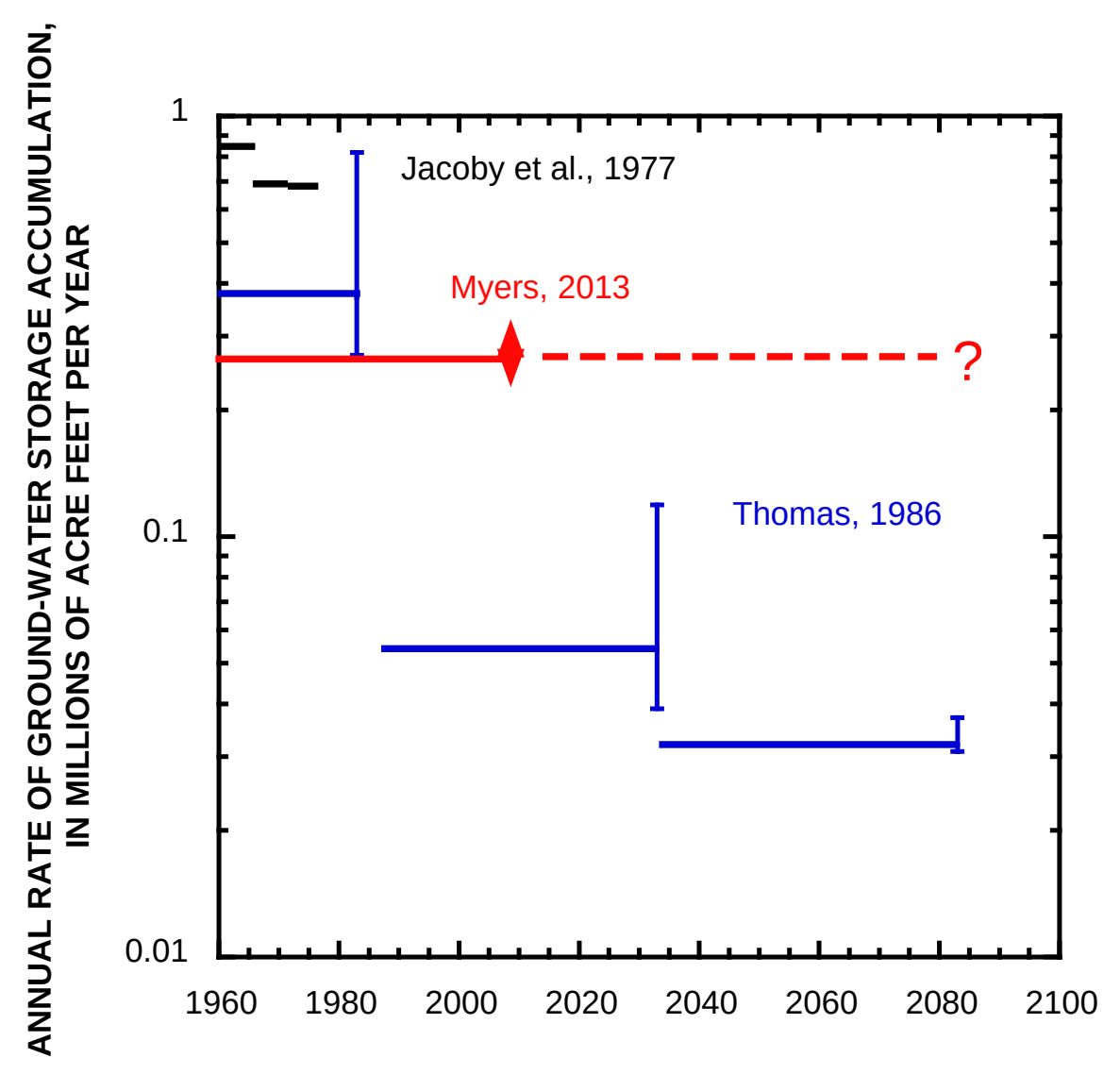
Blanchard, 1986

Thomas, 1986

Thomas, 1986



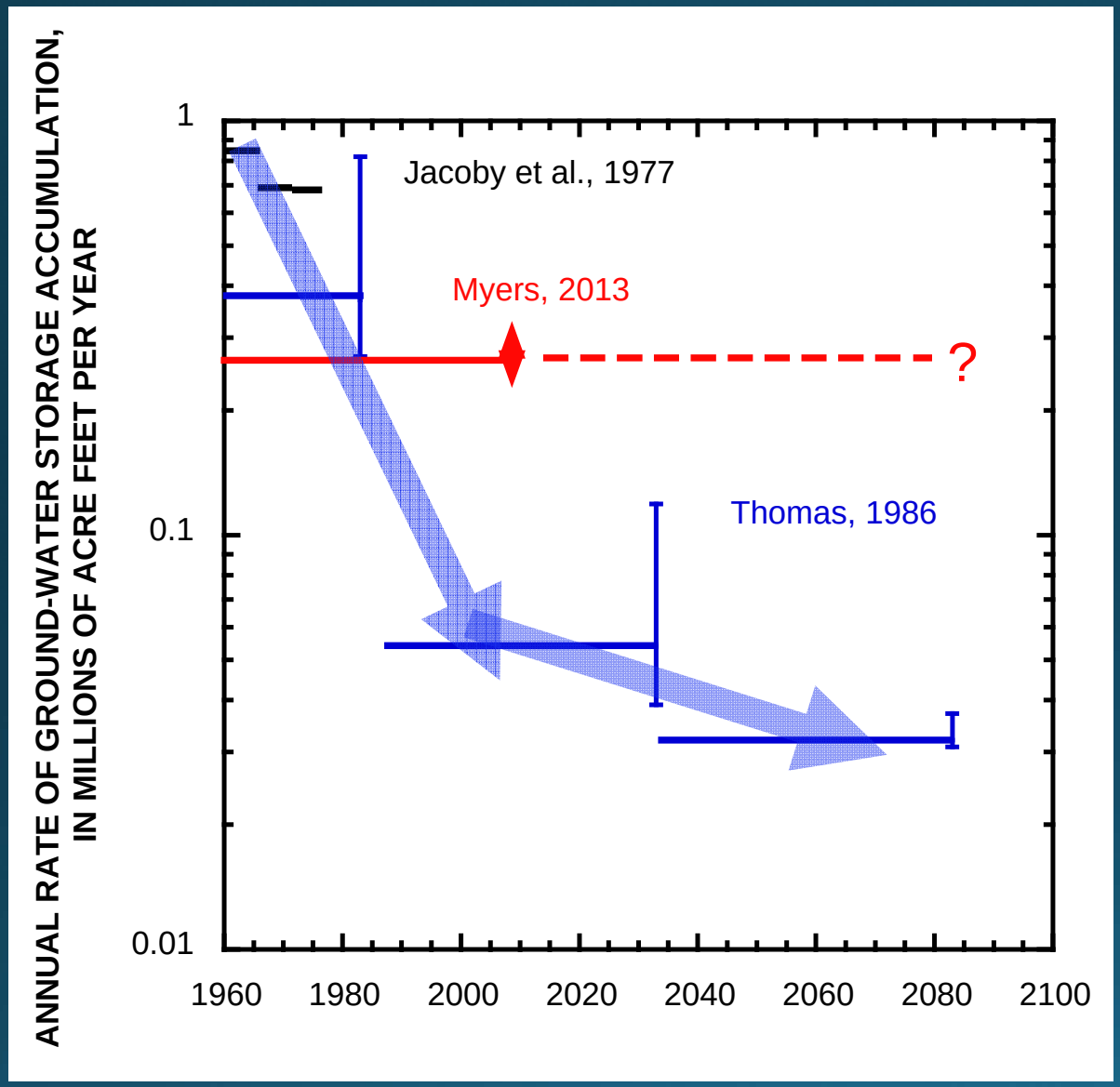
Estimated perturbations of ground-water flow near Glen Canyon Dam



Estimated water savings associated with lowering or draining Lake Powell are based on assuming that past rates of ground-water storage will continue in the future.

This is unlikely.

Future ground-water movement estimated 50,000 af/yr, decreasing to 30,000 af/yr after mid-century.



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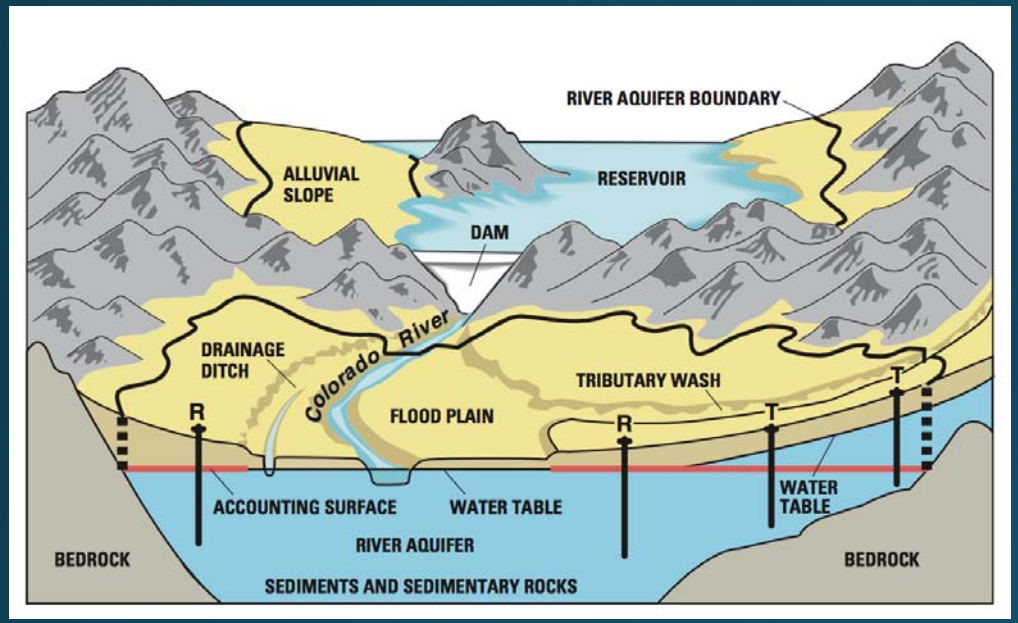
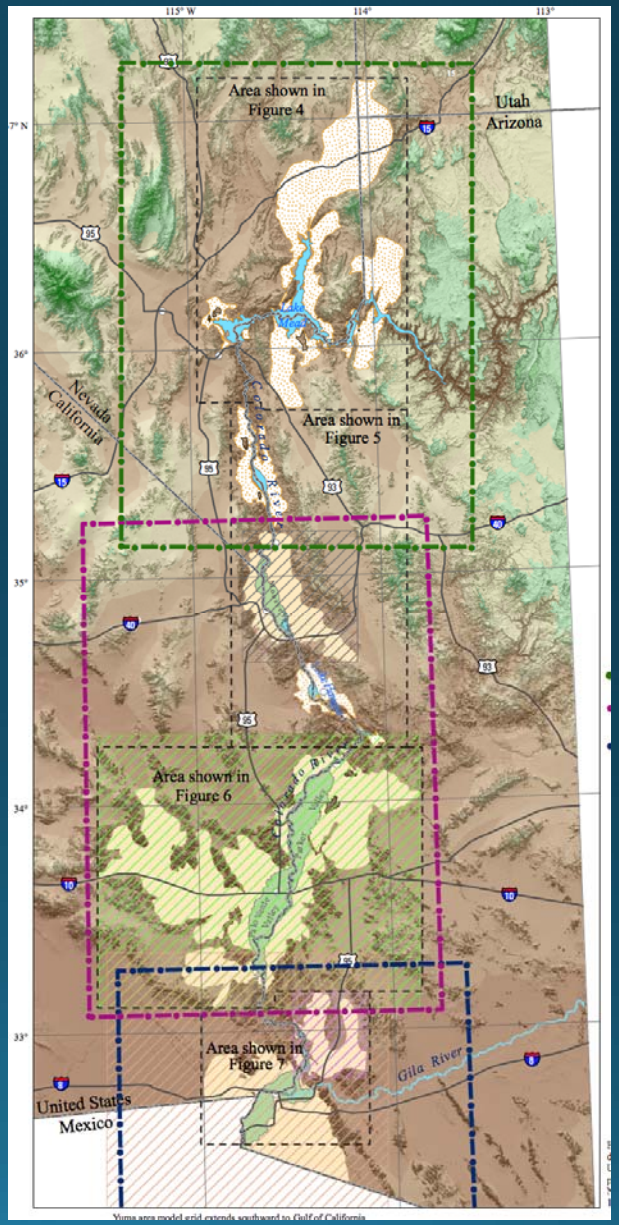
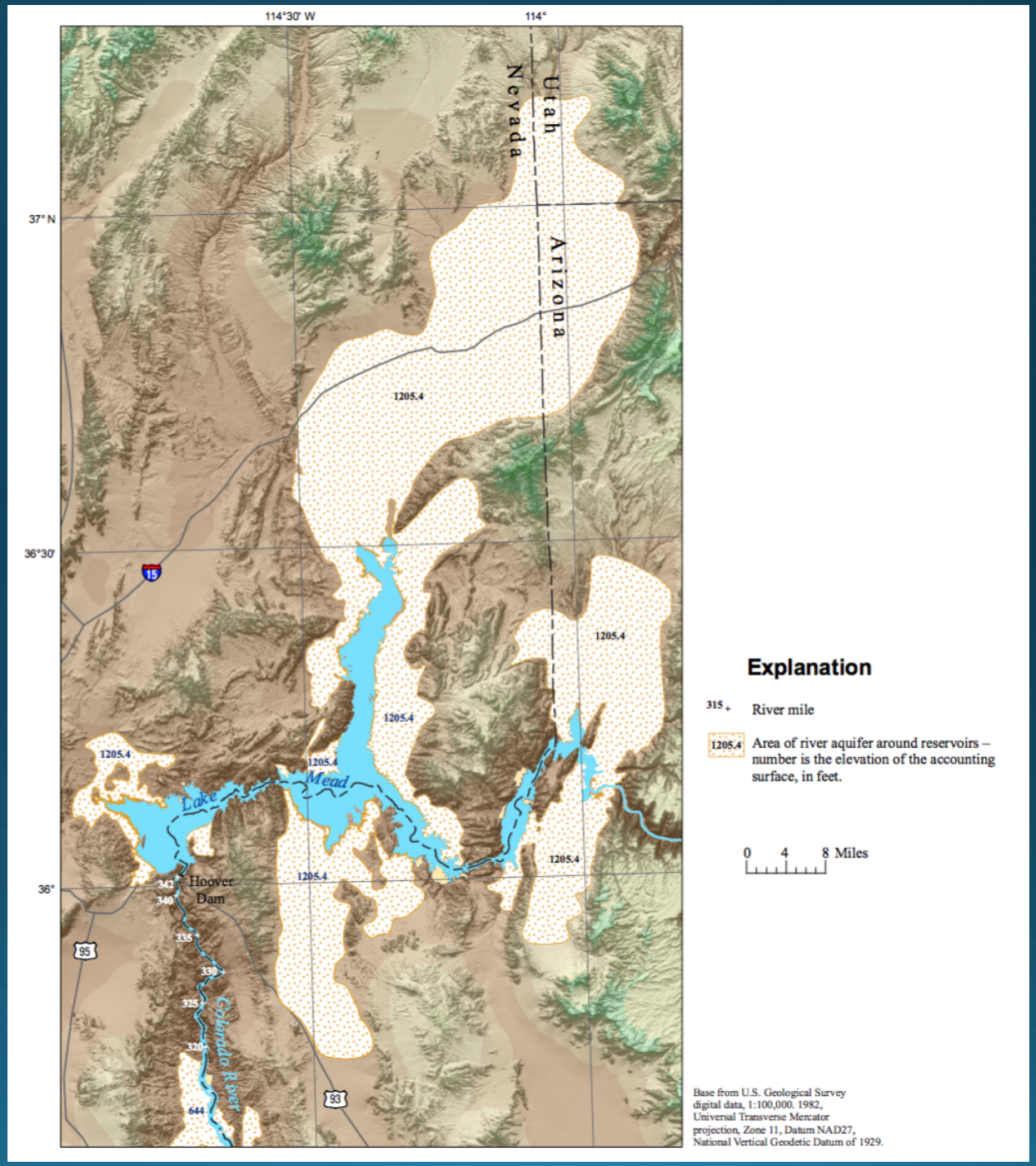




Accounting surface defines those wells distant from the river and reservoirs whose water partly comes from the Colorado River

Wiele et al., 2009

Although the spatial extent of the saturated alluvium has been defined, no modern studies of ground-water movement have been conducted.



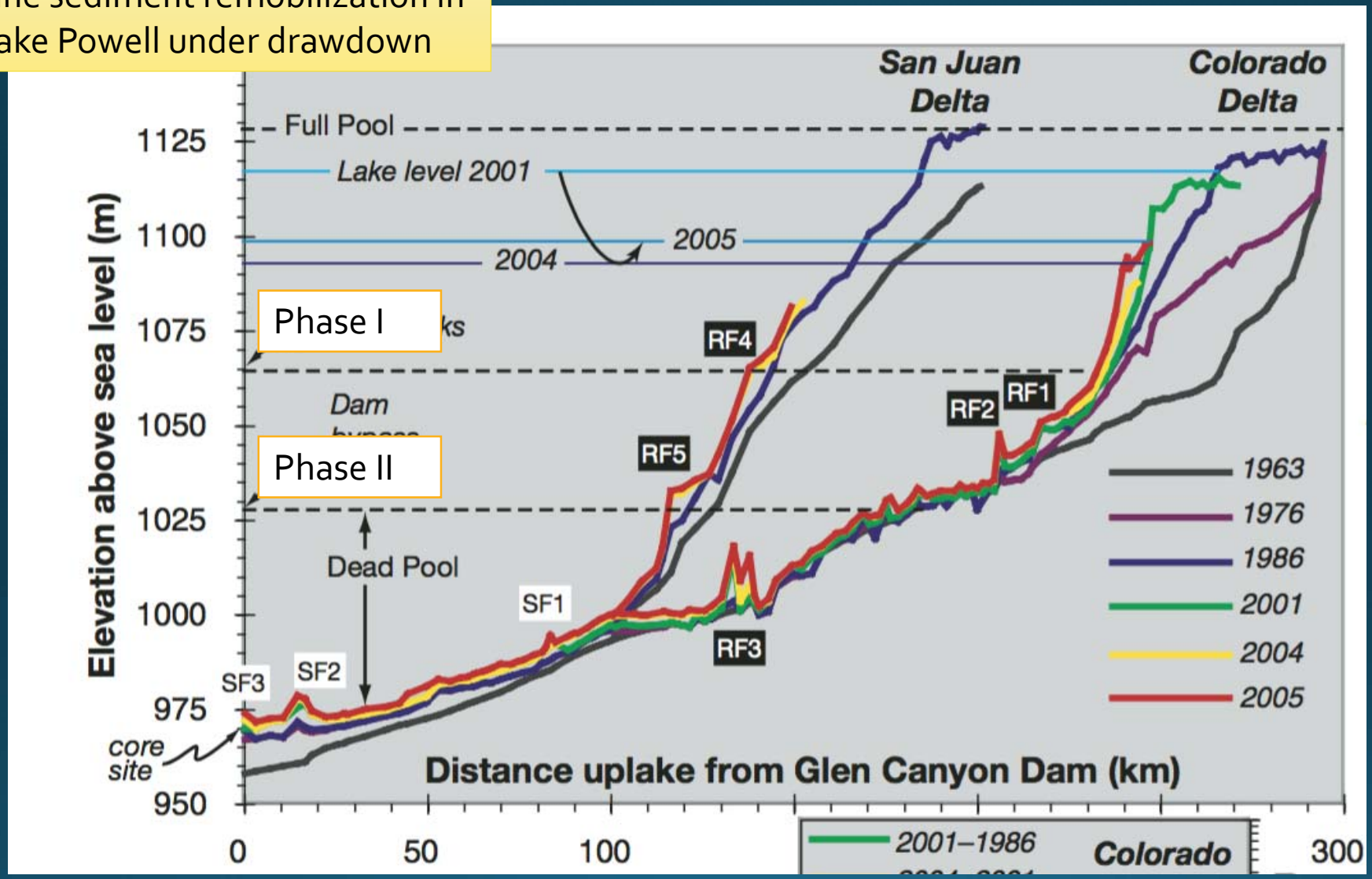
Wiele et al., 2009

Conclusions Concerning Ground Water at Lake Powell

- Ground water moves from Lake Powell into the surrounding Navajo sandstone.
- The rate that ground water moves into the surrounding bedrock is relatively slow and is likely to have declined with time.
- Most studies have estimated that equilibrium conditions are likely to take many centuries to develop. A proportion of ground-water storage is better considered long-term bank storage and is not available to meet decadal-scale water supply needs.
- Changes in ground-water storage are likely to occur as far as 20 miles from the reservoir.
- There is no evidence of bank seepage losses from Lake Powell, except around the north side of Glen Canyon Dam. That water seeps back into the Colorado River upstream from Lees Ferry.
- No studies have described ground-water movement south from Lake Powell or around the south side of Glen Canyon Dam.

Fine sediment remobilization in Lake Powell under drawdown
March 2004, near Hite Marina.

Fine sediment remobilization in Lake Powell under drawdown

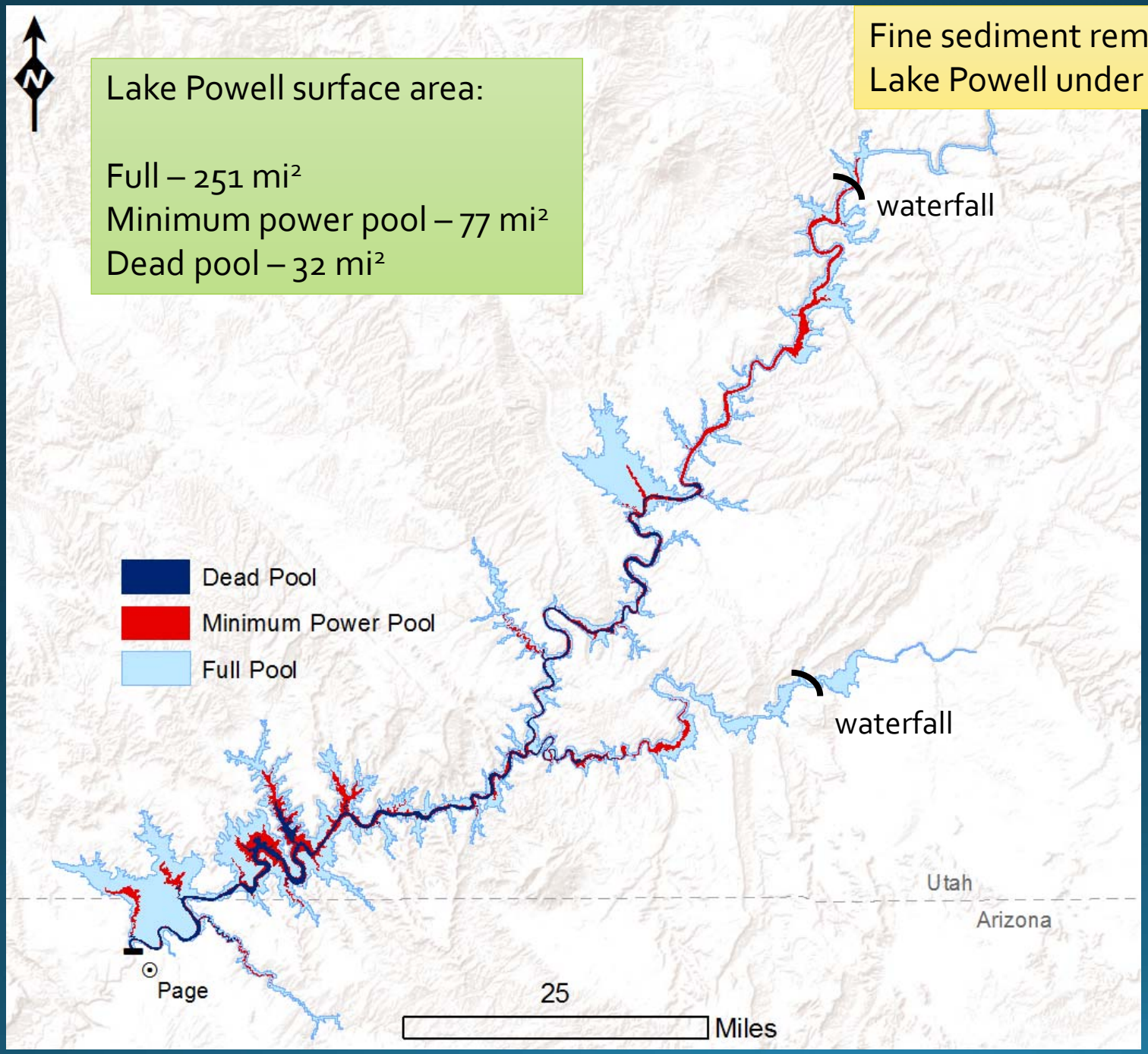


The lower reservoir levels of Phase I and Phase II would cause the San Juan and Colorado Rivers to incise into their deltas. The mobilized fine seidment would form new deltas within the lowered reservoir. Downstream releases would be clear water.

Fine sediment remobilization in Lake Powell under drawdown

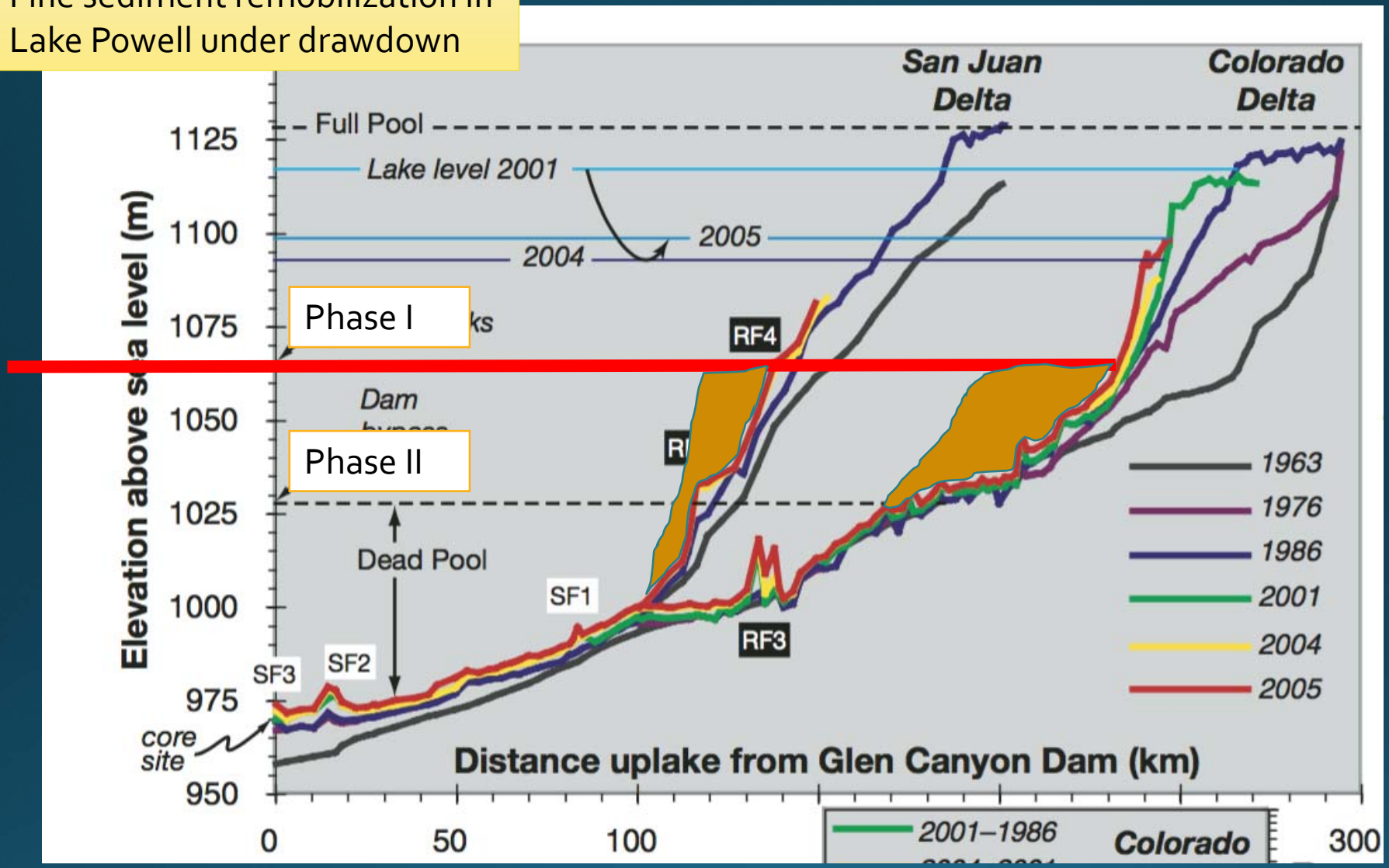
Lake Powell surface area:

Full – 251 mi²
Minimum power pool – 77 mi²
Dead pool – 32 mi²



D. Tuzlak

Fine sediment remobilization in Lake Powell under drawdown



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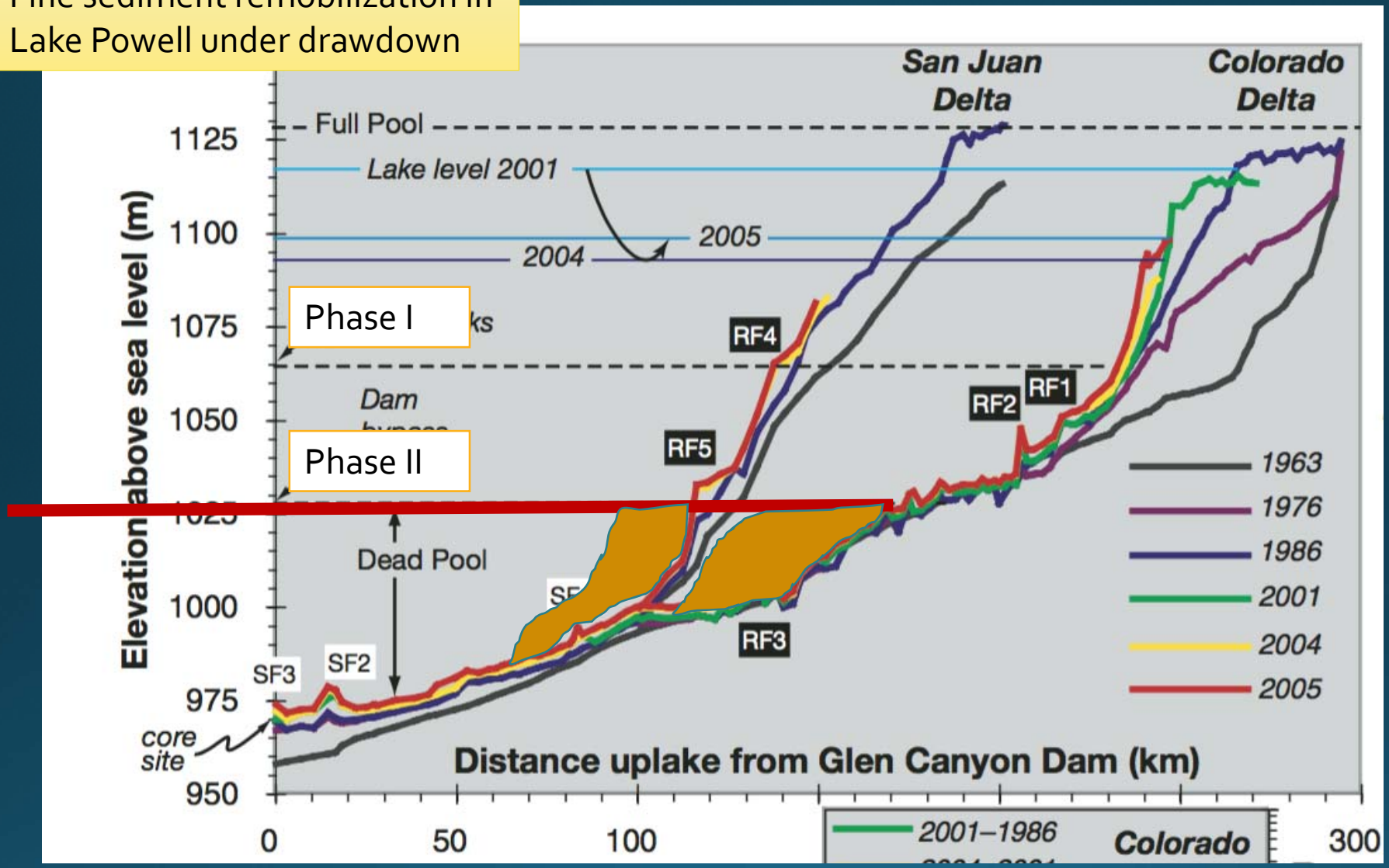
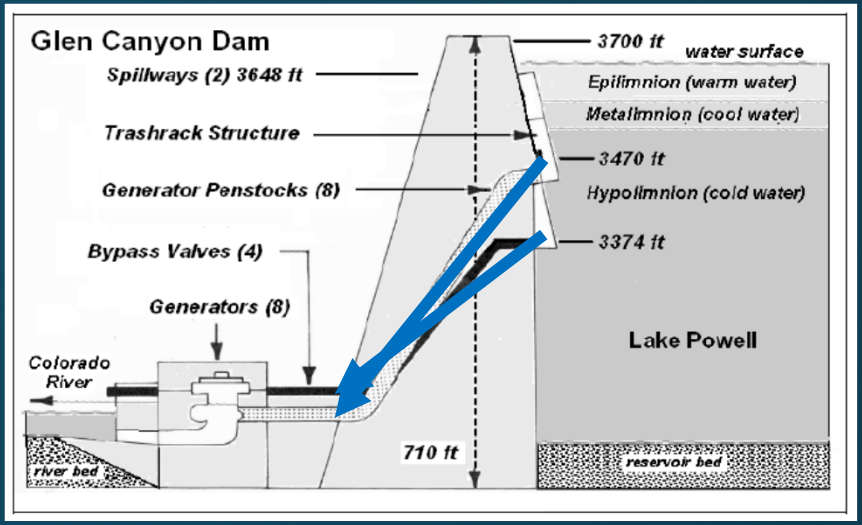
Fine sediment remobilization in Lake Powell under drawdown

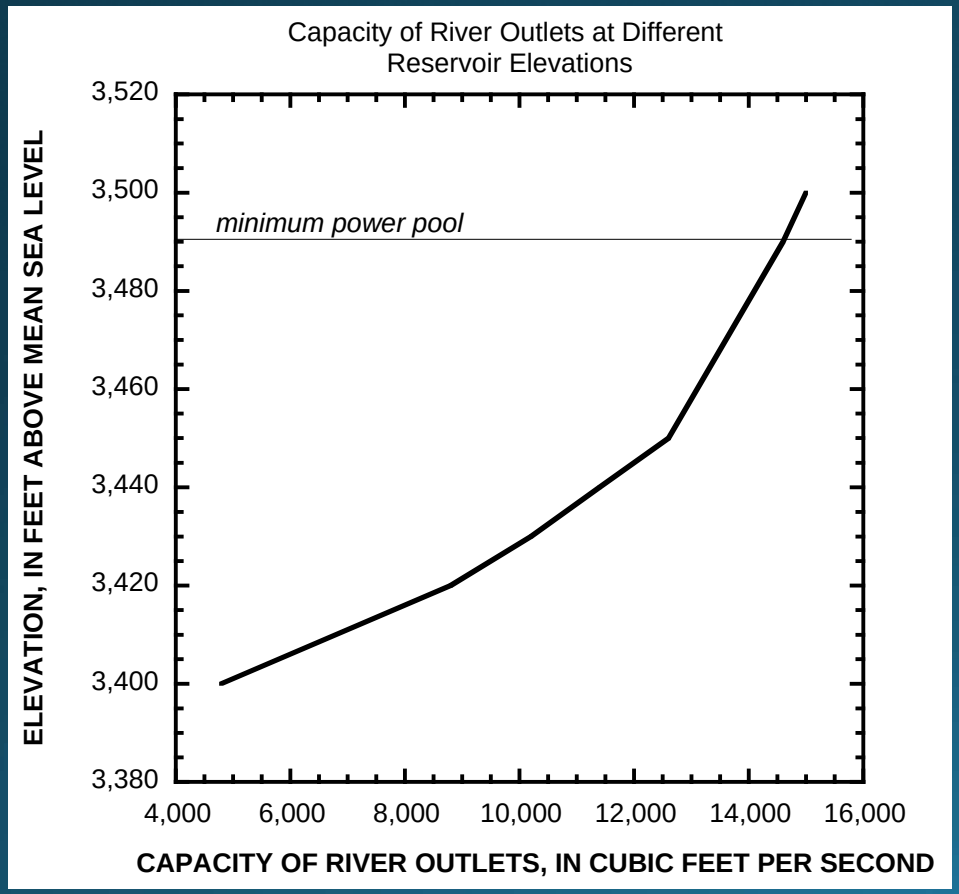


The lower reservoir levels of Phase I and Phase II would cause the San Juan and Colorado Rivers to incise into their deltas. The mobilized fine seidment would form new deltas within the lowered reservoir. Downstream releases would be clear water.

The capacity of the infrastructure limits the ability to reestablish a natural flow regime.



capacity of penstocks ~31,500 ft³/s



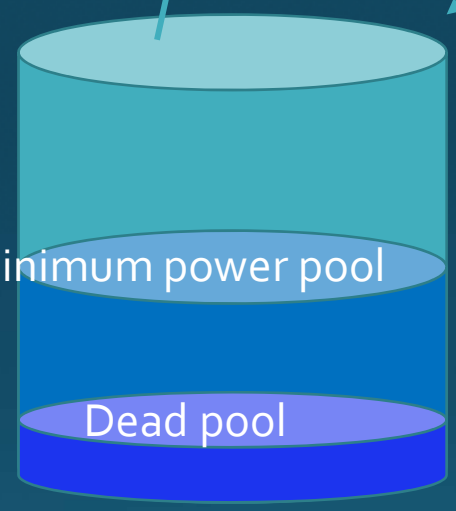
capacity of river outlets is 15,000 ft³/s when reservoir is above minimum power pool elevation; below mppe, capacity is much less

Data: Bureau of Reclamation

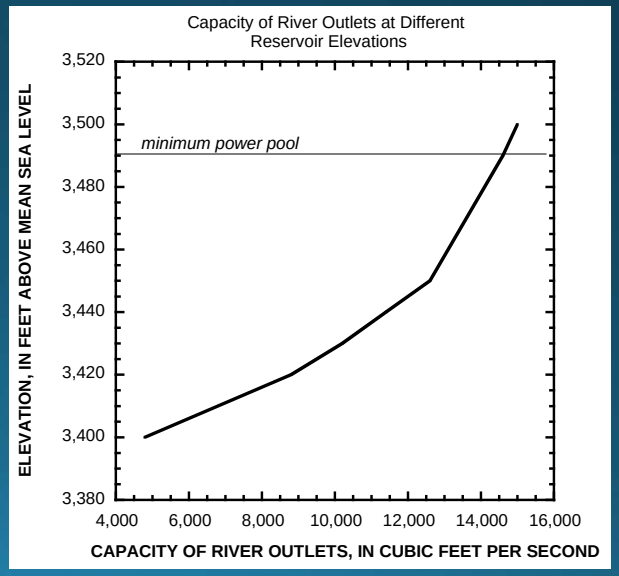
Inflow (observed hydrology)

Evap

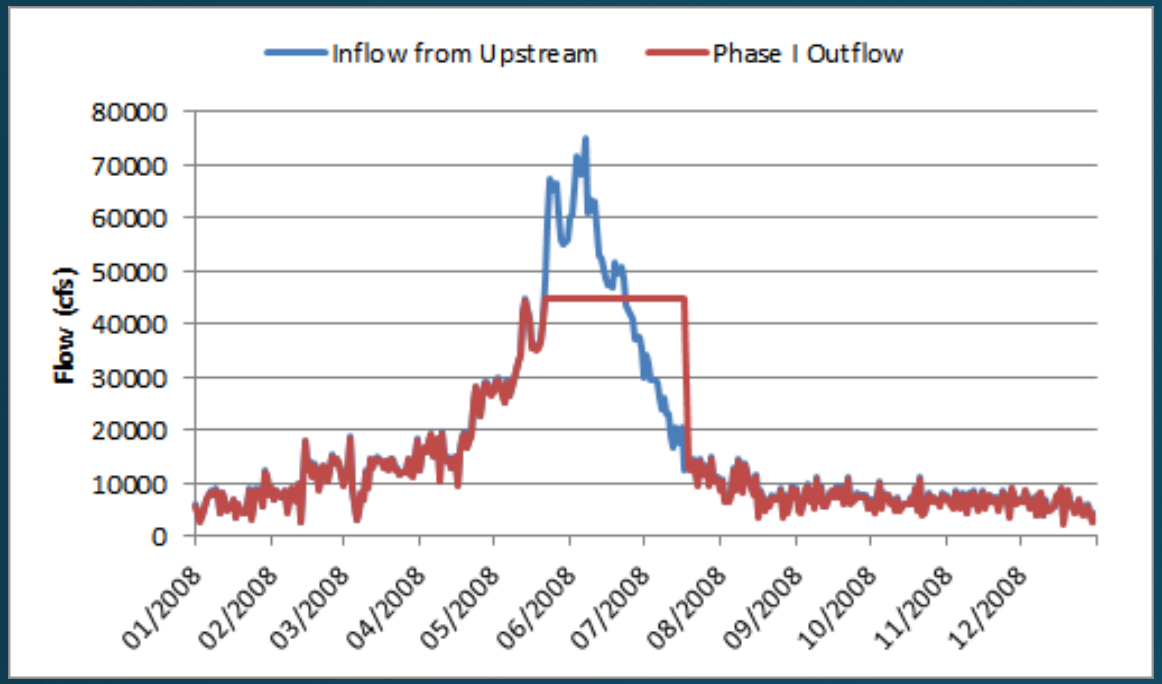
Power-plant release rule: match inflows; maximum release is 31,500 ft^3/s



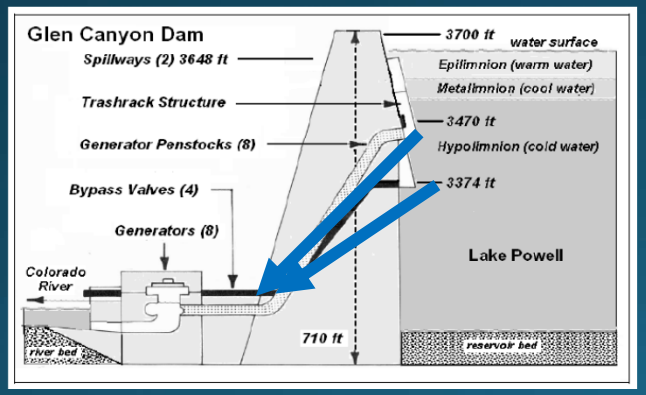
Rule curve for releases through river outlets

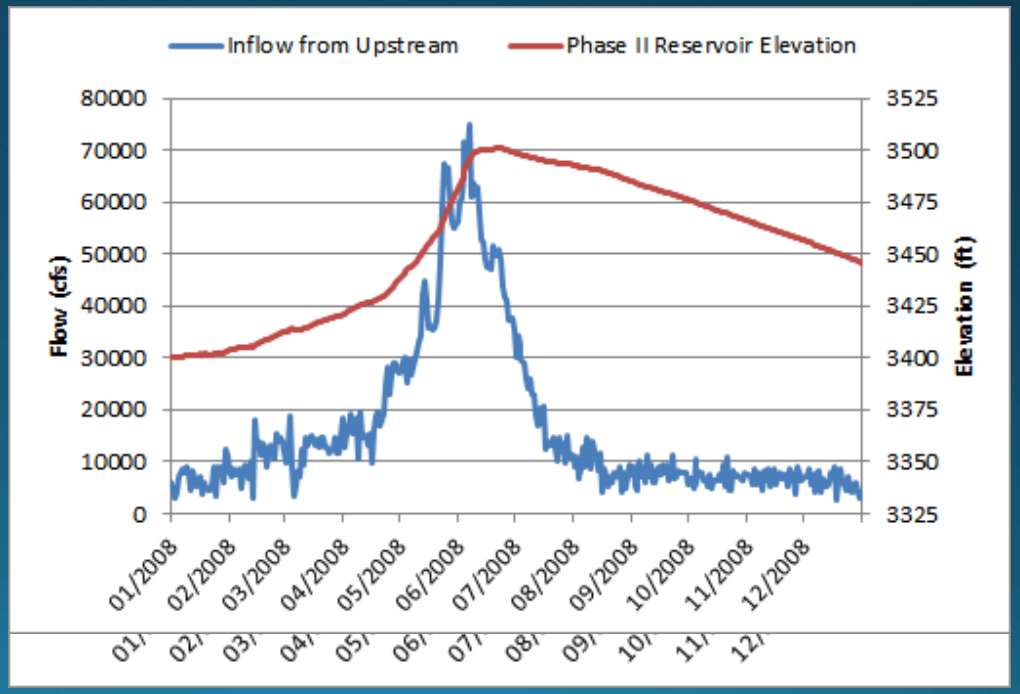


River outlets: maximum release 15,000 ft^3/s

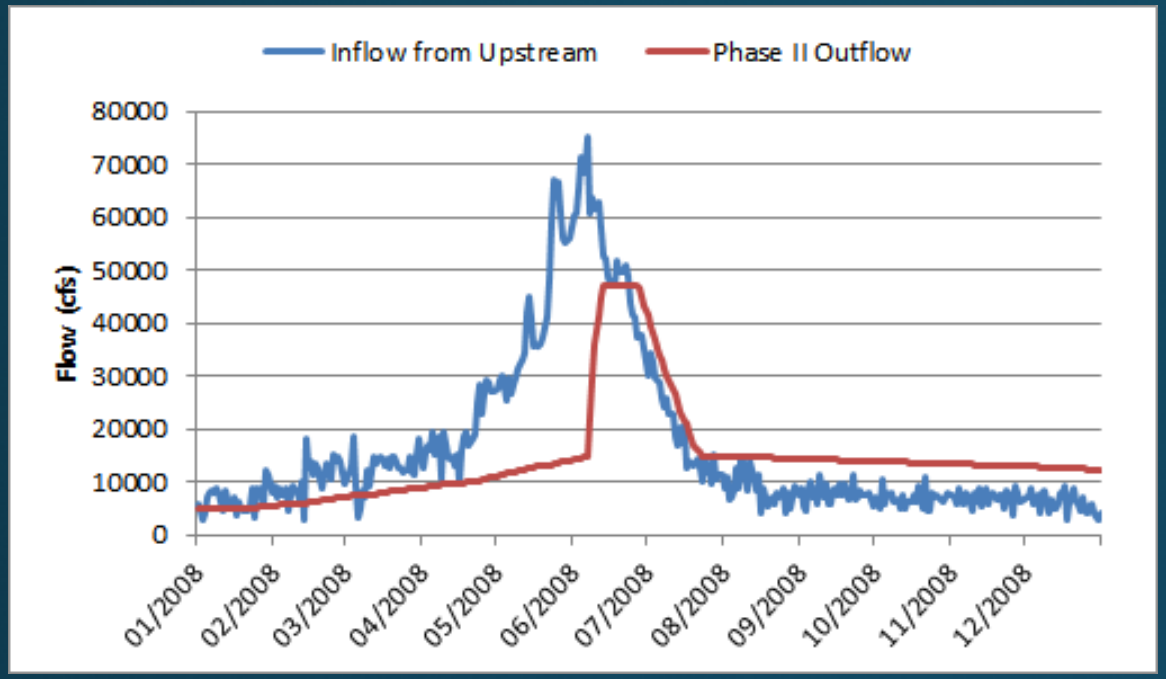


In Phase I of FMF, part of the incoming snowmelt flood would be temporarily stored in Lake Powell

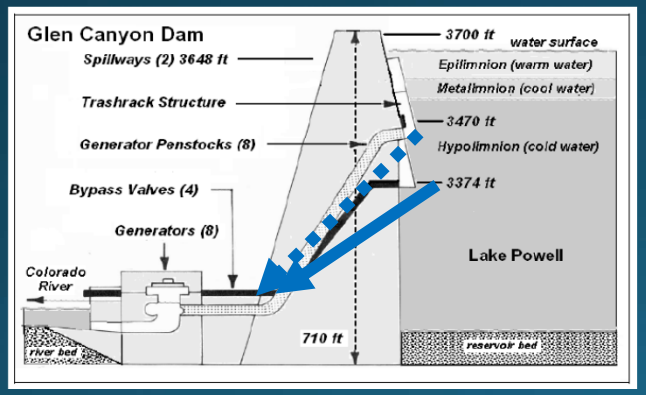


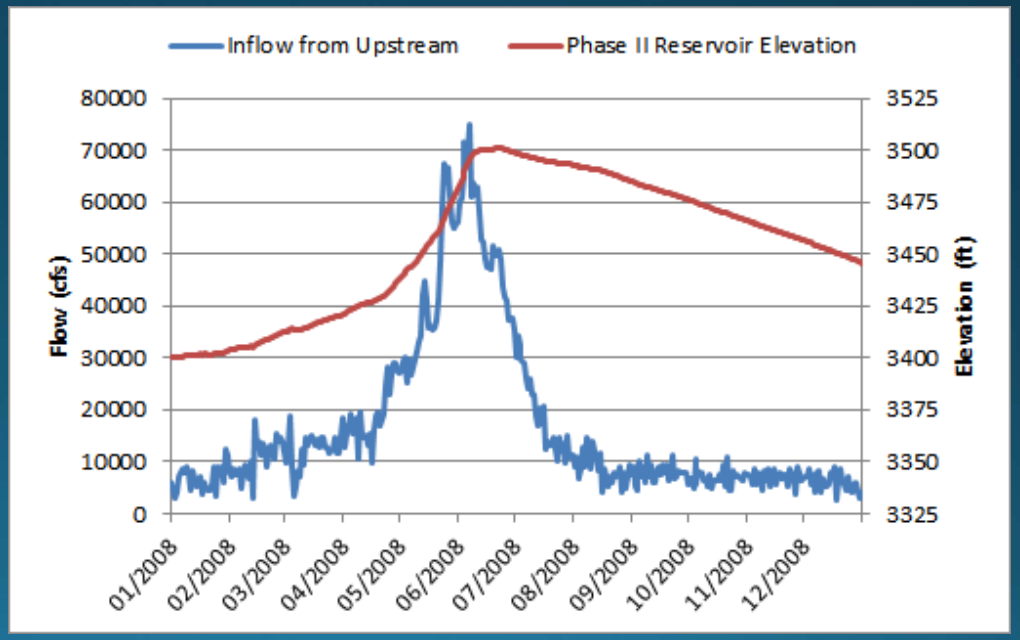


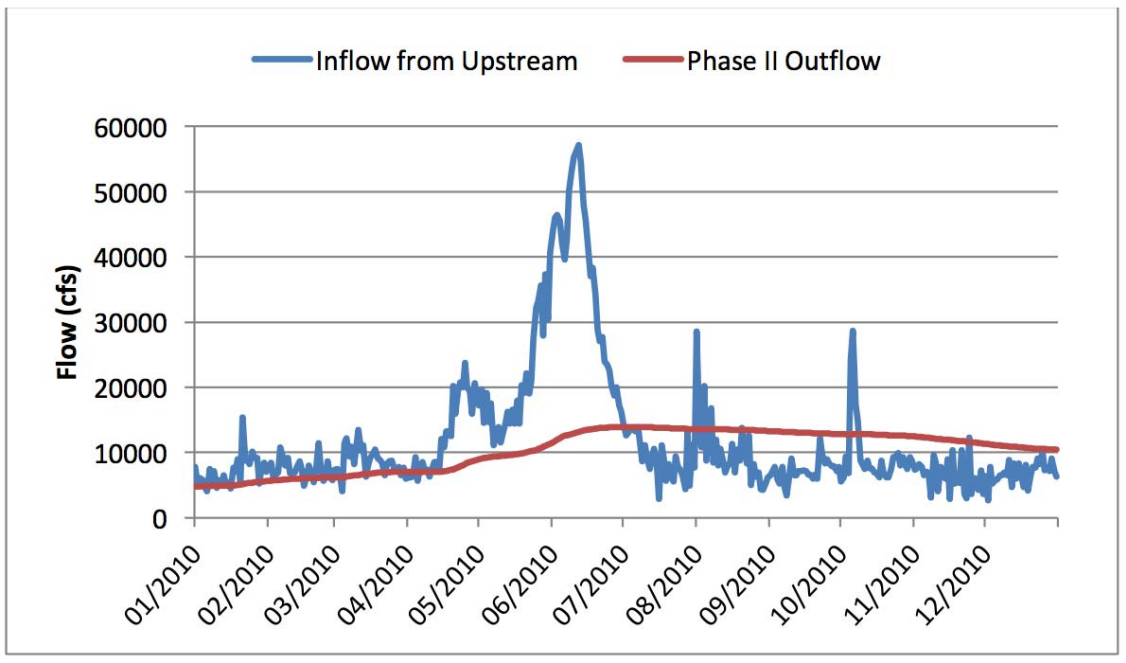
M. Kraft



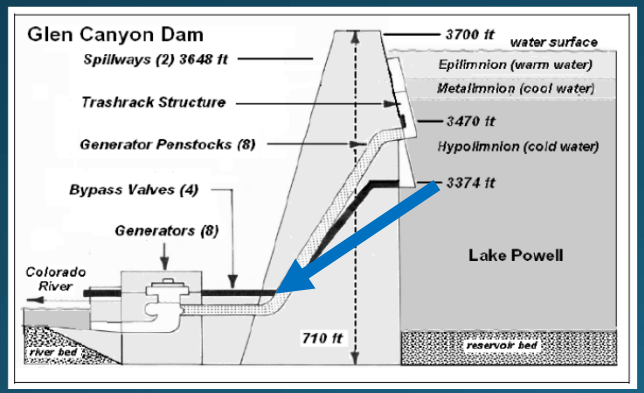
In Phase II of FMF, a large part of the incoming snowmelt flood would be stored in Lake Powell in above average years. Reservoir levels would not return to dead pool within the year.

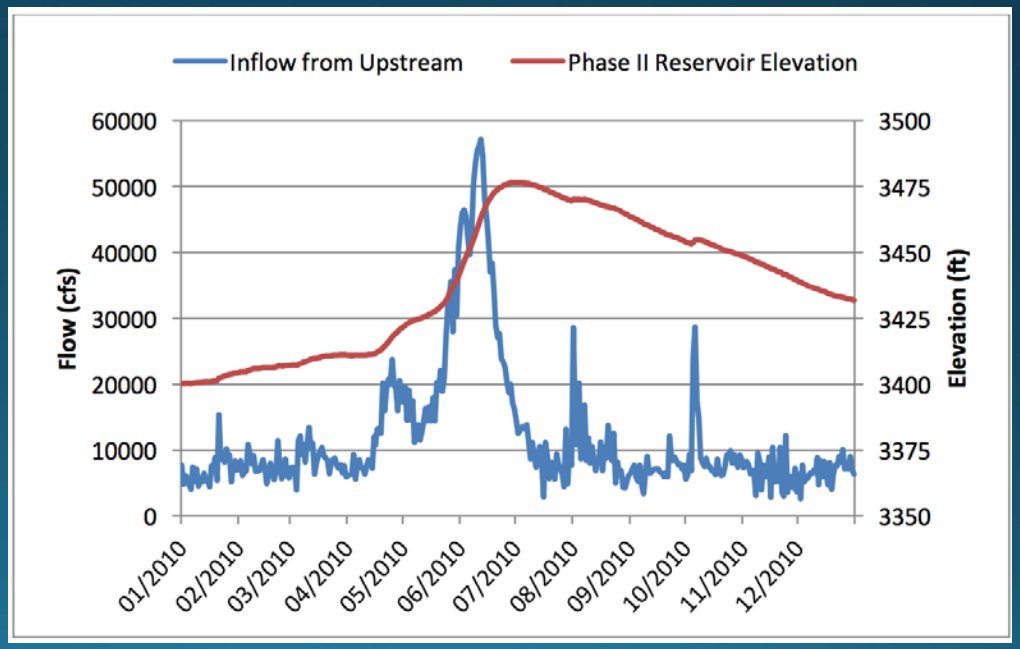


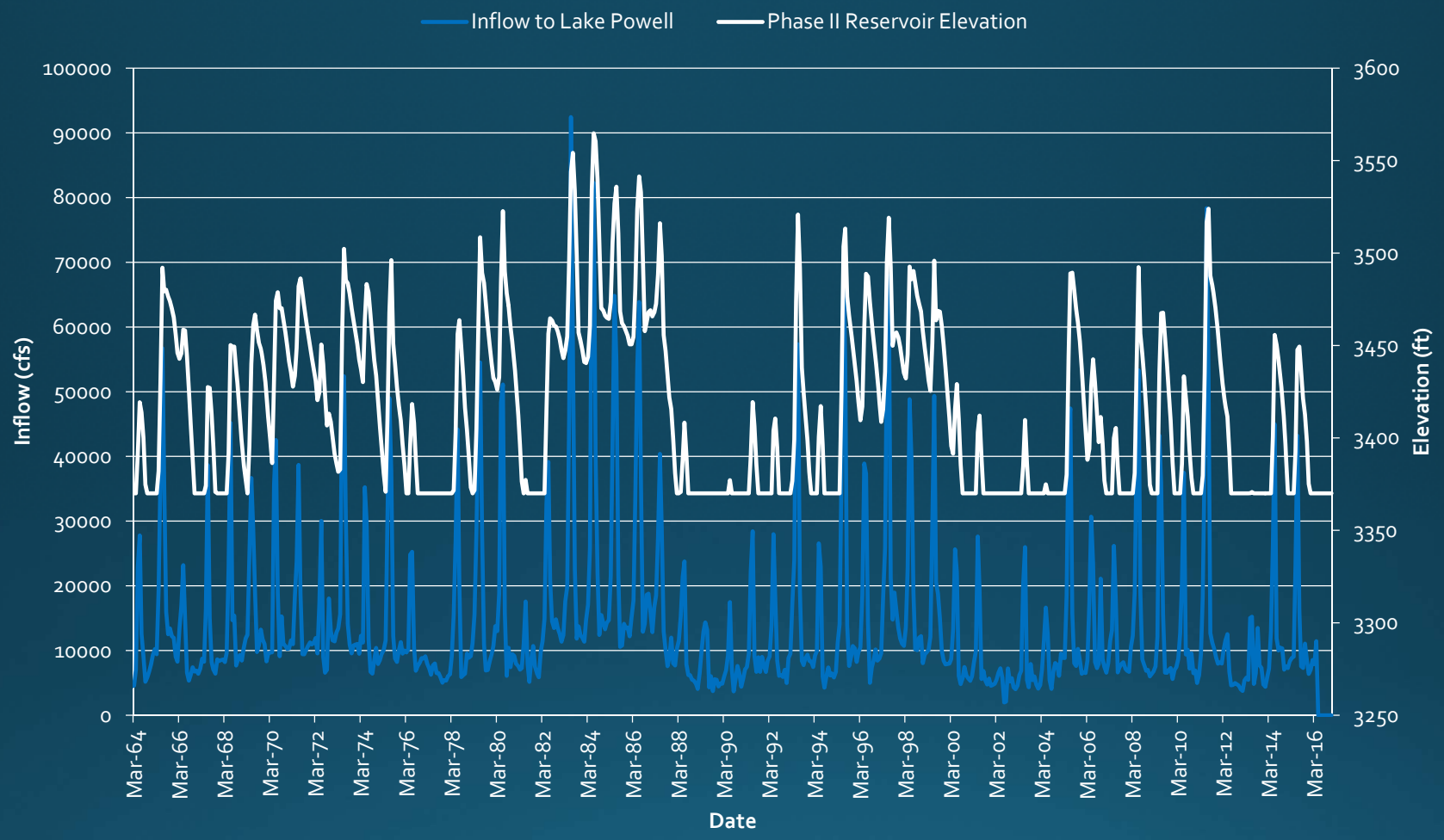




In Phase II of FMF, a part of the incoming snowmelt flood would be stored in Lake Powell in slightly below average years. Reservoir levels would not return to dead pool within the year.

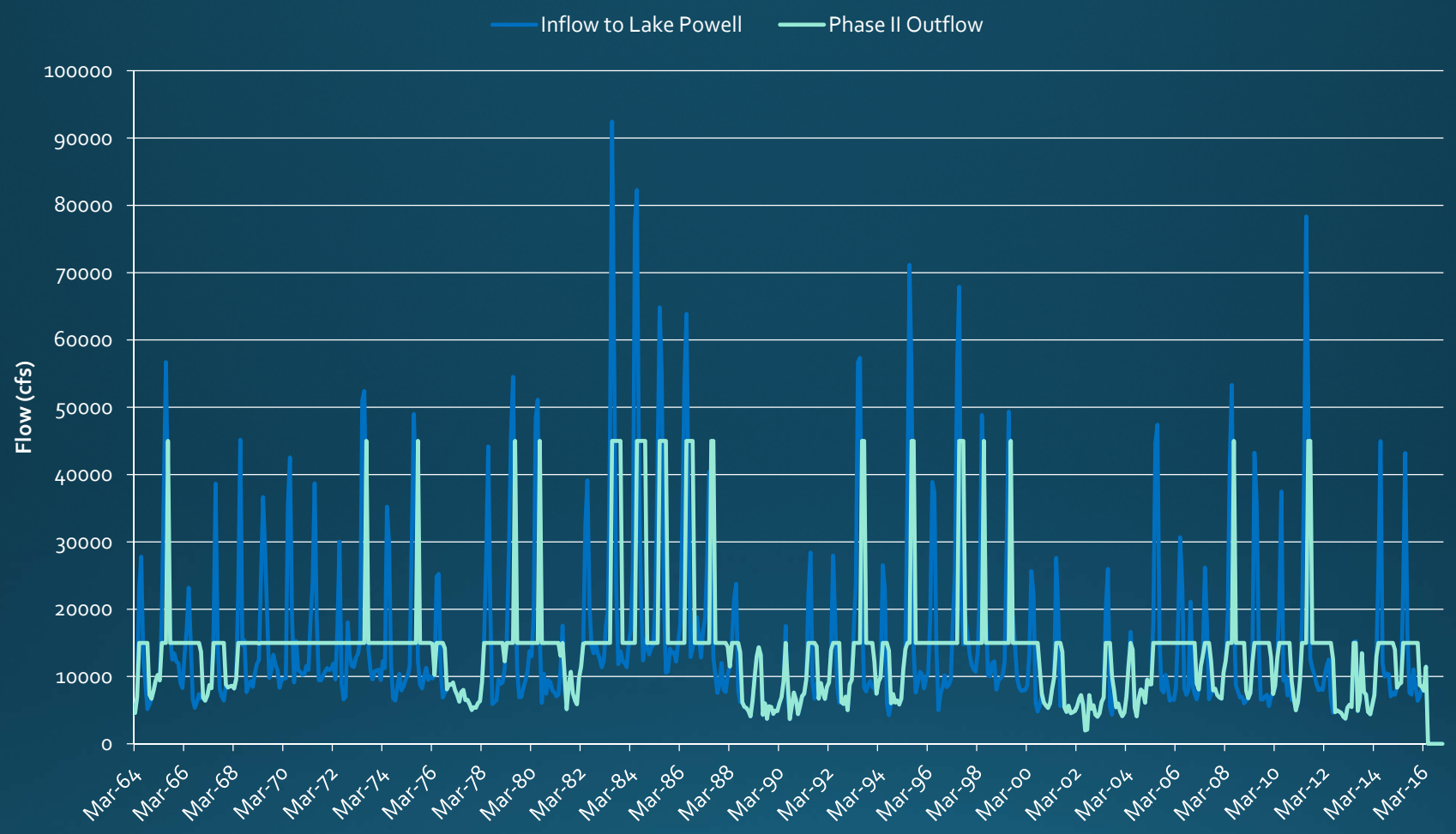






In Phase II of FMF, Lake Powell would rarely be at dead pool elevation

M. Kraft



The flow regime in Grand Canyon would be very different from the natural regime in Phase II.

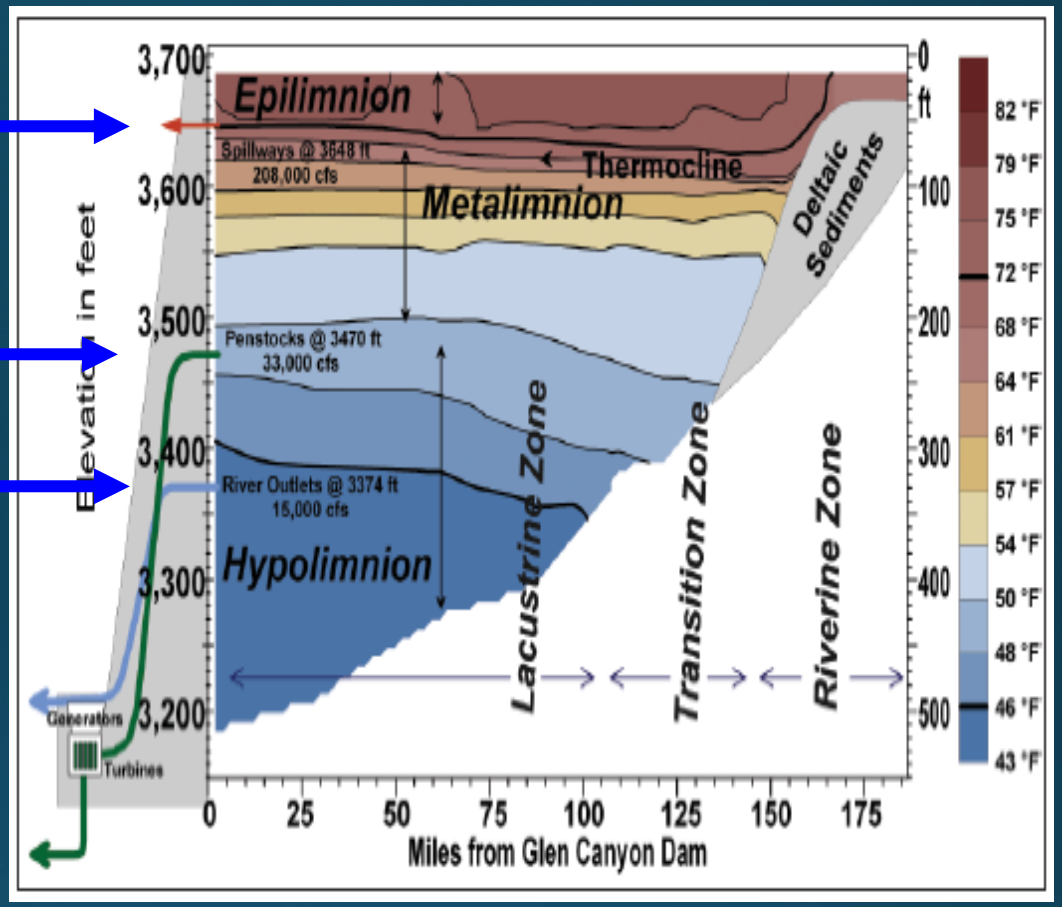
Potential to increase sediment deficit in Grand Canyon.

M. Kraft

Spillways – 3648’
(Warm)

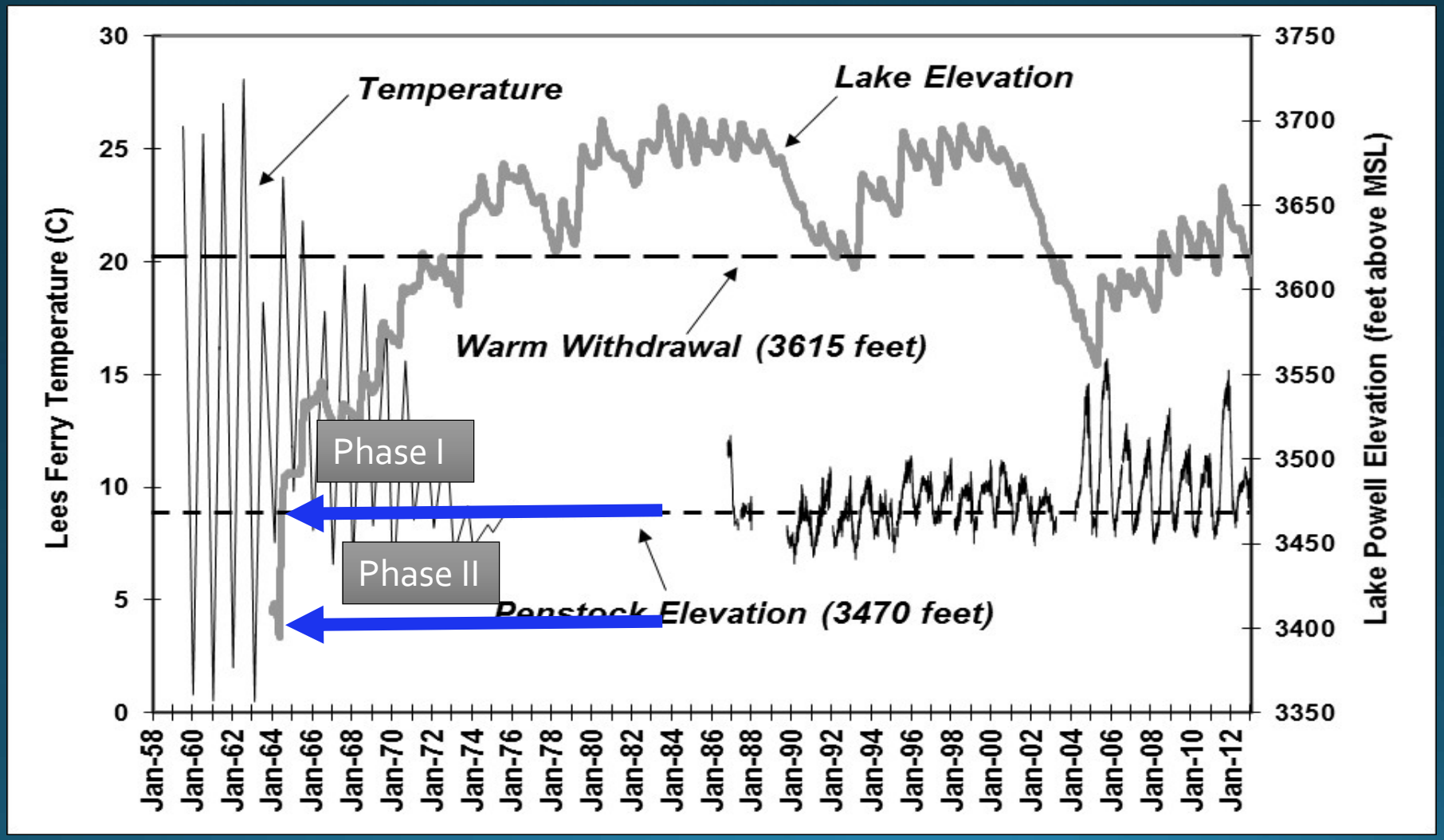
Powerplant – 3470’
(Cold/Warm)

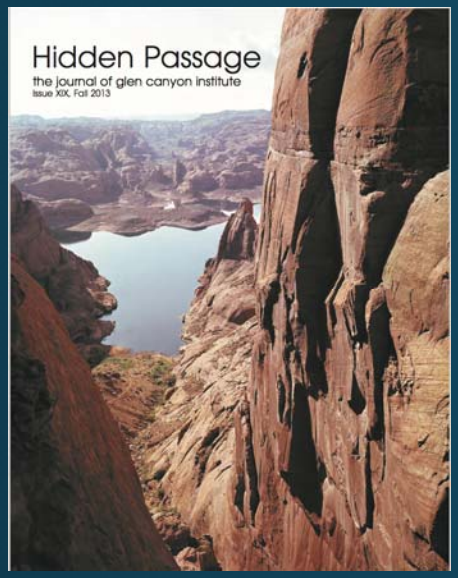
River Outlets – 3374’
(Cold)



As reservoir level declines, releases downstream will warm.

It is likely that there would be significant within-year temperature fluctuation under Phase I and Phase II. There would be significant warming during summers.





Findings:

Implementation of Phase I or Phase II of FMF is unlikely to re-establish a natural flow regime of the Colorado River in Grand Canyon

Water released from a partially drained Lake Powell in Phase I or Phase II is likely to be devoid of fine sediment. Impacts to the aquatic and riparian ecosystem, including to the existing population of endangered humpback chub, are potentially significant and would have to be monitored and managed adaptively.

There is likely to be no change in total reservoir evaporation losses if FMF was implemented.

Based on the best estimates of the most recent USGS study, the long-term future rate of movement of ground water into the bedrock surrounding Lake Powell is likely to be less than ~50,000 af/yr.

Now is the time to initiate new measurement programs of losses at Lake Powell and Lake Mead so that future policy discussions have access to less uncertain data regarding evaporation and ground-water storage

- initiation of a new measurement program of evaporation at Lake Powell
- continuation of the present evaporation measurement program at Lake Mead
- initiation of a new phase of ground-water monitoring and modeling at Lake Powell and perhaps at Lake Mead, including establishment of new observation wells further from and to the south of Lake Powell, coupled by development of modern, state-of-the-science numerical models of ground-water flow
- establishment of a new gaging station to reduce uncertainty in estimating the amount of unmeasured inflow to Lake Powell
- implementation of FMF would have to be preceded by predictive modeling of fine-sediment redistribution within a partially drained Lake Powell so that reservoir releases would not further degrade the Grand Canyon ecosystem.