CONCEPTUAL RULE-BASED STORAGE ACCOUNTING FOR MULTIPURPOSE WATER RESOURCE SYSTEMS

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Abstract: Rule-based storage accounting provides a framework for efficient and equitable allocation of the benefits, costs and risks associated with operation of multipurpose federal reservoir systems through (1) policies and procedures for exchange of storage among included purposes, and (2) a system of credits and penalties associated with storage use designed to prevent cross-subsidization among included purposes and to check unsustainable demands on storage. Rule-based storage accounting does not allocate water or storage, but defines procedures to ensure operational compliance with allocation formulas agreed upon by users of storage or included purposes.

The principal features of rule-based storage accounting are listed as follows:

- Quantitative accounting of all demands on conservation storage based on established purposes, storage allocation, and system operating rules, priorities and constraints
- Tracking and adaptation of reservoir system operating rules, instream flow requirements and water demands to ensure operational compliance and recovery of over-utilized storage

By giving all included purposes a stake in the management of the reservoir system, rule-based storage accounting provides an opportunity for parties in river basin water allocation or management conflicts to achieve consensus on water allocation formulas initially, and for participatory management of the Basins and comprehensive water planning thereafter.

Rule-based storage accounting applies to consumptive and non-consumptive uses of water, and provides a practical means to allocate benefits, costs and risks of water management under riparian, appropriative and hybrid river basin management systems.

INTRODUCTION

Rule-based storage accounting provides a practical framework for efficient and equitable allocation of the benefits, costs and risks associated with operation of multipurpose reservoir systems through (1) policies and procedures for exchange of storage among included purposes, and (2) a system of credits and penalties associated with storage use designed to prevent cross-subsidization among included purposes and to check unsustainable demands on storage. Rule-based storage accounting does not allocate water or storage, but defines procedures to ensure operational compliance with allocation formulas, objectives, priorities and constraints previously agreed upon by stakeholders. Uses of storage are also referred to as 'included purposes.' The principal features of rule-based storage accounting are listed as follows:

- Quantitative accounting of all demands on conservation storage based on established purposes, storage allocation, and system operating rules:
    - Consumptive and non-consumptive uses of water and/or storage
    - Conjunctive and disjunctive water demands
    - Instream flow requirements
- Tracking and adaptive management of the reservoir system and water demands for the following purposes:
    - Recovery of system conservation storage depleted by reservoir releases or diversions in excess of amounts required to meet individual purpose or common operational requirements
    - Monitoring of compliance by operators, water managers and users with established water allocation formulas, water rights and operational priorities
    - Reconciliation of operating rules and/or demands with current conditions to limit and equitably allocate the cumulative impacts of over- or underutilization of storage

- o Incentivization of demand management strategies to promote conservation and maximize yield of watersheds and allocated storage

Rule-based storage accounting procedures subsequently described apply principally to conservation uses of water and storage, under the assumption that conservation objectives are normally superseded by flood control requirements. Formulation of storage accounting procedures for physical reservoir systems is a straightforward process, and virtual accounting procedures may also be developed and implemented in unregulated river basins having little or no conservation storage.

PROCEDURES FOR RULE-BASED STORAGE ACCOUNTING

Generic rule-based storage accounting for multipurpose river and reservoir systems is accomplished in stepwise fashion as follows:

(1) Baseline sequential simulation model(s) are collaboratively developed to track system operations and demands on water and storage within the system. Models should have the following basic components:
   - o System rule base, i.e. logical and/or mathematical at-site and system operational objectives, constraints, prior-cities, and storage allocations
   - o Physical system data in sufficient detail to enable management of the system for conservation and flood-control purposes
   - o Consumptive and non-consumptive water demands, instream flow requirements, reservoir levels and other operational constraints for all purposes including hydropower, water supply, water quality, river and reservoir recreation, species protection, species and ecosystem protection, environ-mental flows, and navigation

   The baseline model represents ‘perfect’ system operations, i.e. determines conservation releases at each time step based on minimum requirements to satisfy all applicable operating rules, instream flow requirements, and water demands, as follows:

$$R_{req} = Min\ \{Max\ R\ \{all\ purposes\}\}$$

(2) Tracking capabilities of the baseline model(s) are validated for all conservation and flood management purposes individually and collectively.

(3) Modification/refinements to system rule base are made as necessary to (1) improve operational performance, i.e. rule curves designed to minimize induced drawdown and refilling of conservation storage, guide curves designed to balance storage among system reservoirs to allocate risk and probabilities of conservation storage refilling, seasonal and contingent power and non-power demands, limiting flood releases and/or minimum instream flow requirements, (2) incorporate drought indicators and drought contingency rules, and (3) define emergencies and special conditions under which storage accounting would be suspended.

(4) Build consensus on the following aspects of rule-based storage accounting policies and procedures:
   - o Allowable deviations from baseline conditions before corrective rule changes are imposed; allowable deviations may be defined for each accounting period (e.g. monthly) as well as cumulative deviations over time.
   - o Circumstances including emergencies, hydrologic forecasting uncertainty, and other errors and omissions under which deviations would be absorbed by all purposes and corrective rule changes would be waived (incorporated into the baseline).
   - o Limits on corrective rule changes and penalties against over-utilizing purposes.
   - o Criteria and procedures for crediting under-utilizing purposes and/or purposes adversely impacted by over-utilizing purposes.
   - o Account-clearing criteria, policies and procedures including emergencies and flood-control operations.

CONCEPTUAL IMPLEMENTATION OF RULE-BASED STORAGE ACCOUNTING PROCEDURES

Rule-based storage accounting procedures, once agreed upon by the parties representing established purposes, may be implemented on a periodic basis to check unsustainable demands on the system by any purpose and to ensure recovery of over-utilized water insofar as possible by the other purposes, particularly those adversely affected.

Conceptually at pre-defined intervals, e.g. monthly, current system storage, actual reservoir releases and diversions would be compared with baseline model hindcasts for the preceding month, with initial conditions defined by the actual state of the system at the beginning of the month. The need for corrective rule change is based on the current state of the system, and the nature of the correction determined by the need to remedy joint and separable impacts, as follows:

- Joint-use impacts, measured as the actual deficit or surplus of end-of-month storage values at each system reservoir and for the system as a whole in relation to allowable deviations from baseline model results.
- Separable impacts, measured by the beneficial or harmful effects of over- and under-releases (both of which may occur) during the previous month (in comparison to baseline model releases) on any included purpose.

The nature of corrective rule changes will normally falling into one or more of the following categories:

- Type 1: Hydrologic and operational uncertainty, i.e. forecasting, streamflow routing, and gage errors affecting all purposes, albeit unequally; corrective rule changes may be (1) waived, in which case end-of-month system storage becomes the starting baseline condition for the next month, (2) implemented without prejudice to any included purpose during the following month, or (3) carried over through the following month for tracking of cumulative deviations and potential deferred action.
- Type 2: Over-utilization by one or more purposes necessitating corrective rule changes that reduce levels of service to purposes benefiting from over-use, in order to restore (within acceptable tolerances) system storage to baseline-simulated levels by the end of the following month.
- Type 3: Under-utilization by one or more purposes potentially requiring rule changes to allocate surplus storage, deferred crediting of storage to conserving purposes, or compensation by purposes benefiting from under-utilization to conserving purposes.

End-of-month imbalances in system storage, i.e. individual reservoirs relatively higher or lower than expected, may be considered to be Type 1 deviations and possibly self-correcting depending upon specific provisions of the baseline rule. As a consequence, corrective rule adjustments would normally not be required in such cases. Accrued imbalances in system storage preventing upstream reservoirs from refilling before downstream reservoirs will reduce yield and increase risks of water shortages system-wide, adversely affecting all included purposes.

Storage accounts would normally be cleared or re-initialized when one or more of the following conditions are in effect:

- System conservation storage is full, i.e. all reservoirs are at their seasonal top of conservation pools.
- Flood-control operations are in effect, irrespective of reservoir levels, e.g. pre-releases from conservation storage or curtailment of conservation releases to reduce or prevent downstream flooding.
- Other operating rules and contingencies agreed upon by the parties representing included purposes trigger suspension of storage accounting and/or clearing of accounts.

Penalties and credits for over- and under-utilization of storage, respectively, could be assessed in the form of rule adjustments, transfer of storage-use rights, or financial compensation, in consideration of potential environmental or economic externalities created as a result.

EXAMPLE STORAGE ACCOUNTING APPLICATION – ACF RIVER BASIN

To demonstrate the basic principles of rule-based storage accounting, a hypothetical baseline operating rule for the Apalachicola-Chattahoochee-Flint River Basin is applied, with need for and form of rule adjustments examined for the previously-described Types 1, 2 and 3 deviations. The ACF River Basin consists of four federal multipurpose reservoirs (Lanier, West Point, W.F. George and Jim Woodruff proceeding downstream), several private power reservoirs in the upper and middle reaches of the Chattahoochee River, and numerous water withdrawals and wastewater returns throughout the system. A location map of the ACF Basin is shown in Figure 1.

Major components of the baseline model include the following:

- Minimum daily instream flows of 750 cfs at Atlanta, 1850 cfs at Columbus
- 1989 ACF Water Control Plan action zones, all reservoirs release to balance conservation storage within zones

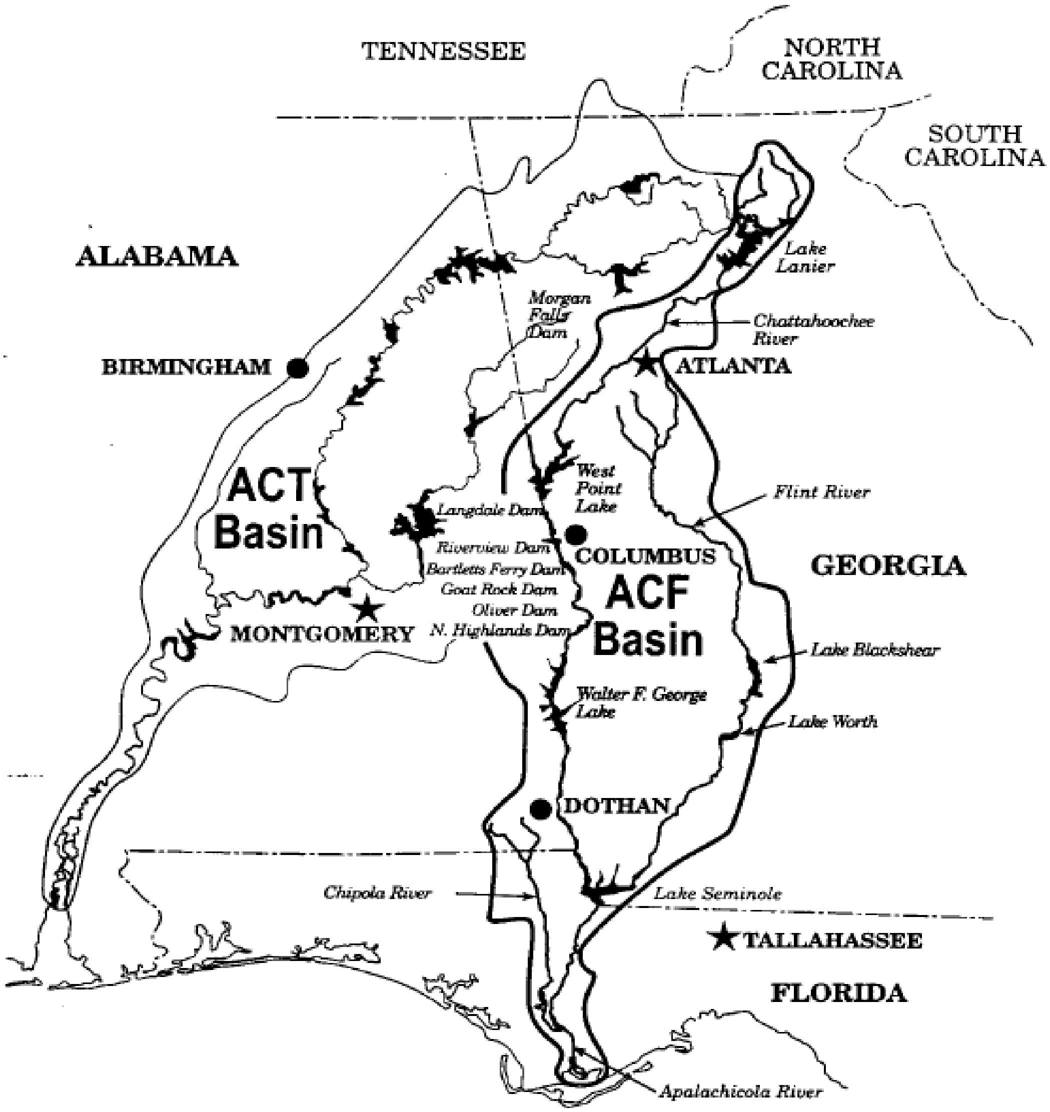

Figure 1: ACF River Basin location map

- Power guide curves – weekday hours of firm power generation requirements in action zones 1 – 4:
  - Lanier: 3, 2, 2 and 0
  - West Point and W.F. George: 4, 2, 2 and 0
- Jim Woodruff: 15% daily plant factor requirement, all zones, 7 days/week
- Measured 2000 water demands (withdrawals and returns)
- Woodruff releases defined by USACE June 2006 modified Interim Operations Plan (IOP)

Conservation purposes considered in ACF Basin management, storage allocation in the Basin's federal reservoirs, water control plans, and day-to-day system operation include hydropower, navigation, river and reservoir recreation, and instream flows for a variety of purposes including water supply and water quality include Other policies and storage-accounting provisions hypothetically agreed to by parties representing these purposes in this example include the following:

- Accounting period – one month
- Allowable monthly excess system storage utilization (combined remaining Lanier, West Point, and W.F. George conservation storage) – 10,000 af
- Maximum carryover storage credit for water demand reductions sue to conservation programs – 10,000 af.

The results of the hypothetical baseline model for April 2006 are shown in Figure 2.

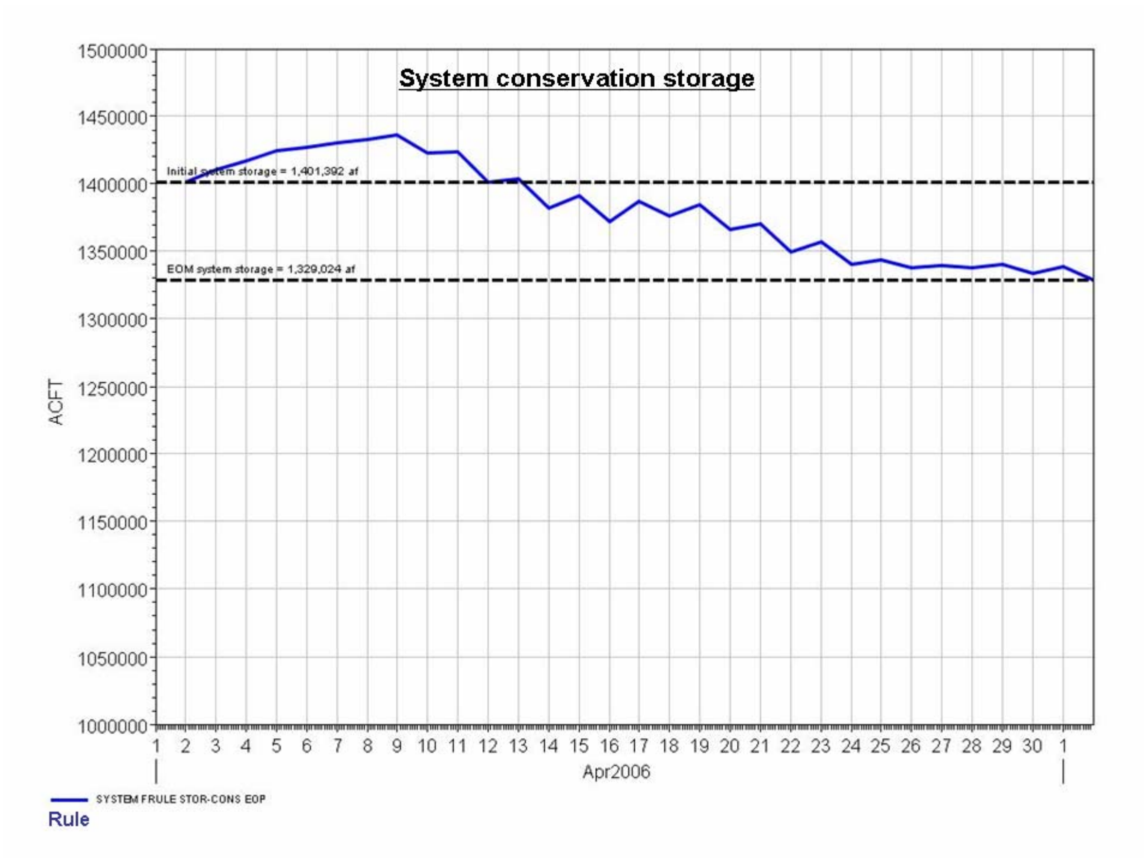

Figure 2: Baseline system storage utilization

Conceptually, observed system storage at the end of April would be compared with baseline model simulation results, and the causes of deviations assessed to determine the need for corrective rule adjustments in May.

Type 1 deviation example: Deviations of this type generally result from hydrologic forecasting and/or operational uncertainty, as opposed to over- or under-utilization of system storage by individual purposes. In this example, Lanier releases are postulated to exceed those required to maintain the 750-cfs minimum flow requirement at Atlanta.

As shown in Figure 3, depletion of system storage in April is small, well under the 10,000-af threshold for corrective action, and in addition the downstream beneficiaries of the over-releases exercise no control over the releases. Consequently no end-of-month (EOM) rule adjustments are necessary in this case. In time, however, excess releases from Lanier (the largest storage reservoir in the system) can shift the balance of storage to the lower reservoirs, substantially drawing down and delaying the refill of Lanier. Thus, failure to correct this imbalance in a timely manner poses serious risks to the users of Lanier and ultimately reduces system yield for all purposes as well result. Prudence dictates the formulation of efficient storage balancing criteria, i.e. criteria that equalize probabilities of refilling all reservoirs insofar as practical, as a component of baseline operating rules. In addition, storage-accounting procedures should provide for periodic operational adjustments to correct cumulative or annual carryover system storage imbalances exceeding pre-defined tolerances.

Type 2 deviation example: In this example, releases from Woodruff Dam to meet environmental flow targets exceed baseline rule requirements of 70% of basin inflow (BI) with a 5000-cfs minimum during spawning season (February – May). Actual releases of 90% BI and 6000-cfs minimum are postulated during April 2006. Figure 4 shows the volume of system storage released in excess of that required by the rule to be slightly more than 25,000 af at the end of April, exceeding the hypothetical allowable deviation of 10,000 af, triggering a corrective rule adjustment in May. While the magnitude of monthly allowable deviations may seem small (< 1% of total system conservation storage, Figure 5 shows the cumulative effect of excess releases could drain more than 40% of remaining system storage in slightly more than 7 months during a dry year if not recovered.

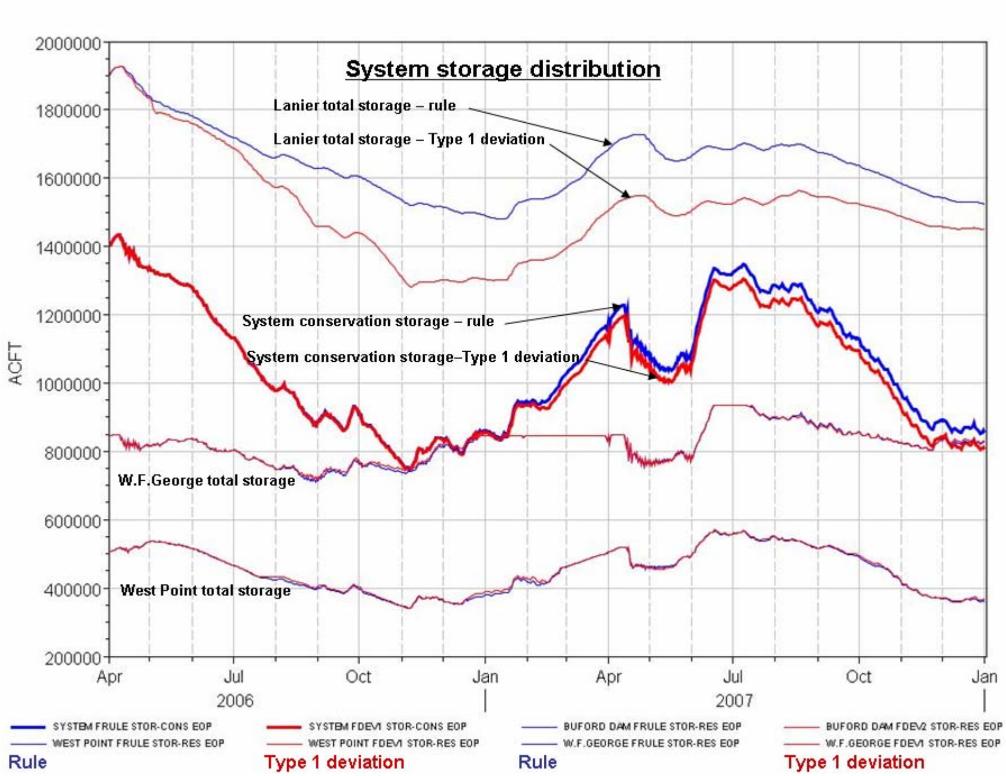

Figure 3: System storage distribution, Type 1 deviation

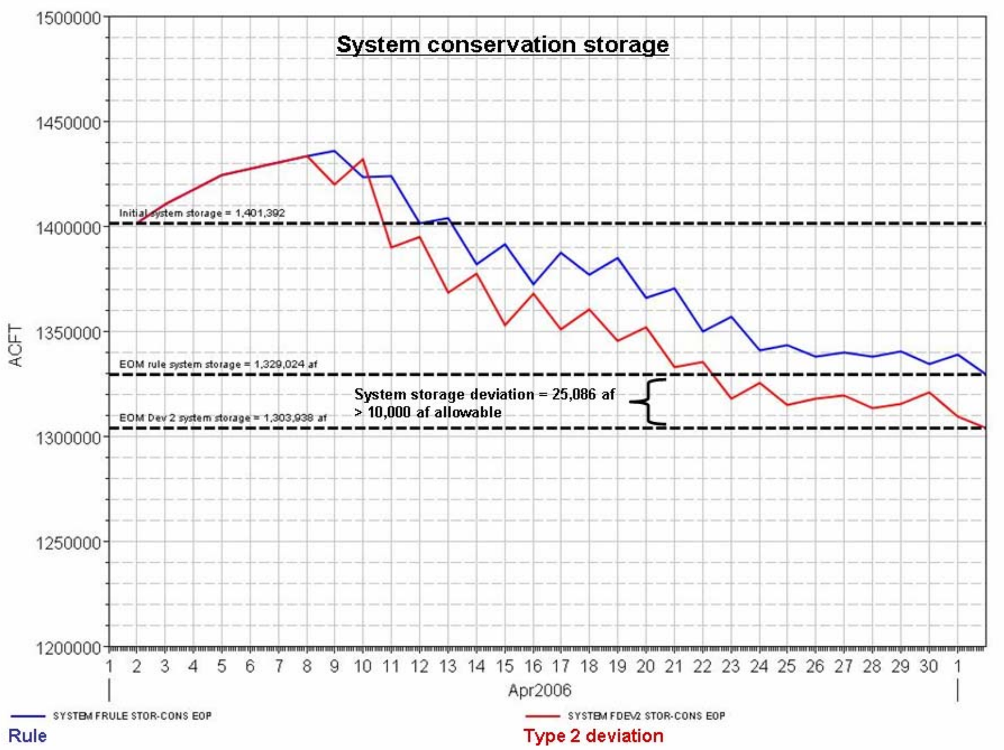

Figure 4: System storage use, Type 2 deviation

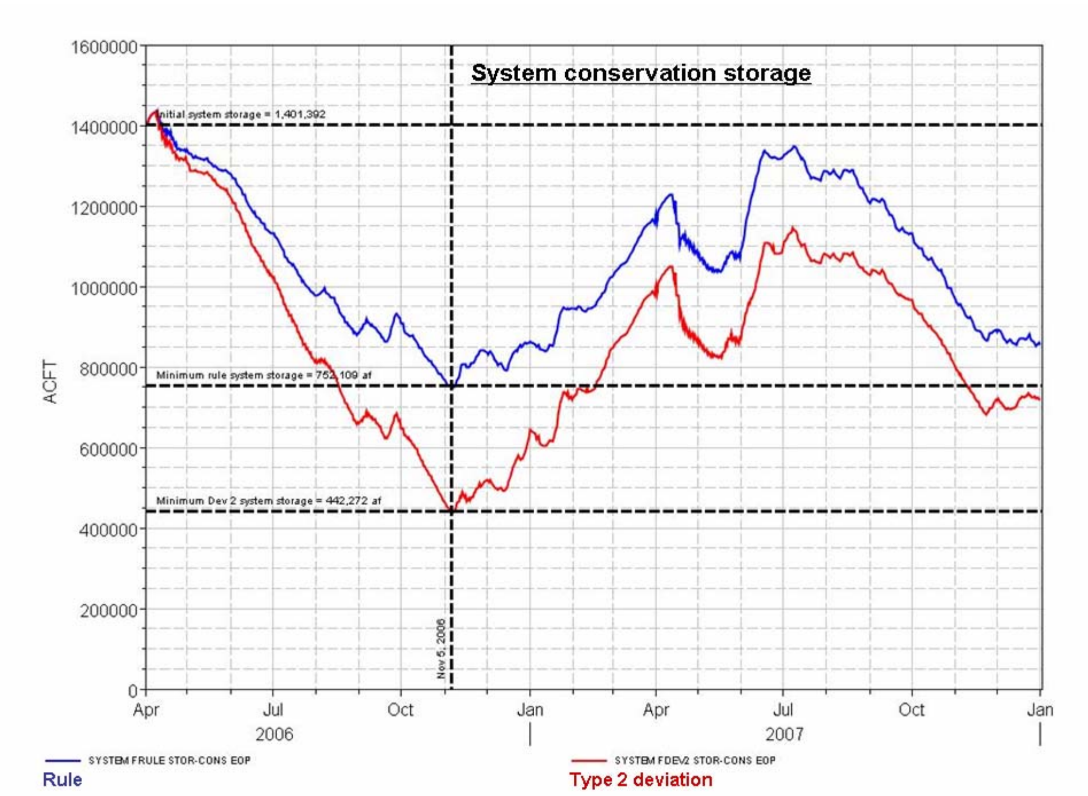

Figure 5: Cumulative long-term storage use, Type 2 deviation

Type 2 corrective rule change: Temporary amendments to the baseline rule are limited to the over-using purpose, in this case environmental flows downstream of Woodruff Dam. The following example amended rules (there are many other possibilities) would apply through May 2006, at the end of which actual system storage will be compared to the rule hindcast. If within allowable system storage deviation tolerances, the corrective rule would be suspended and baseline rule operations resumed. Over- or under-corrections of the rule resulting in system storage deviations from the rule in either direction may be remedied by further iterative interim rule adjustments in subsequent months. The following rule change, provided as an example, permits system storage to recover to baseline rule levels (within acceptable limits) by the end of May:

- Spawning season (March – May): 50% BI variable MIF when BI >10,000 cfs (vs. baseline 70% of BI when BI > 20,400 cfs)
- 5000-cfs minimum floor MIF when BI < 10,000 cfs (vs. baseline 100% BI when BI > 5,000 cfs, 5000-cfs minimum)

The corrective rule change is illustrated in Figure 6, and the effects of corrective rule application in Figure 7. Note the baseline rule allows for very little refilling of system storage in April and May, and system storage is thus very sensitive to releases in excess of minimum requirements during this period. The corrective rule allows for most of April over-releases to be recovered in May to the benefit of all purposes at the expense of the over-using purpose (environmental flows).

Type 3 deviation: As previously described, Type 3 deviations involve under-utilization of storage by one or more purposes. For most purposes, for example municipal water supply, system operating rules would limit storage utilization to the lesser of permitted withdrawals or actual demand. Rules for hydropower and navigation purposes might likewise specify minimum seasonal firm power or reservoir release targets, limited by demand. Under-utilized storage as a consequence of low natural demand would not necessarily be automatically credited to the affected purposes. However, managed demand reductions achieved through conservation programs or investments may be credited or 'banked' for utilization in future months, subject to expiration period and storage account clearing criteria.

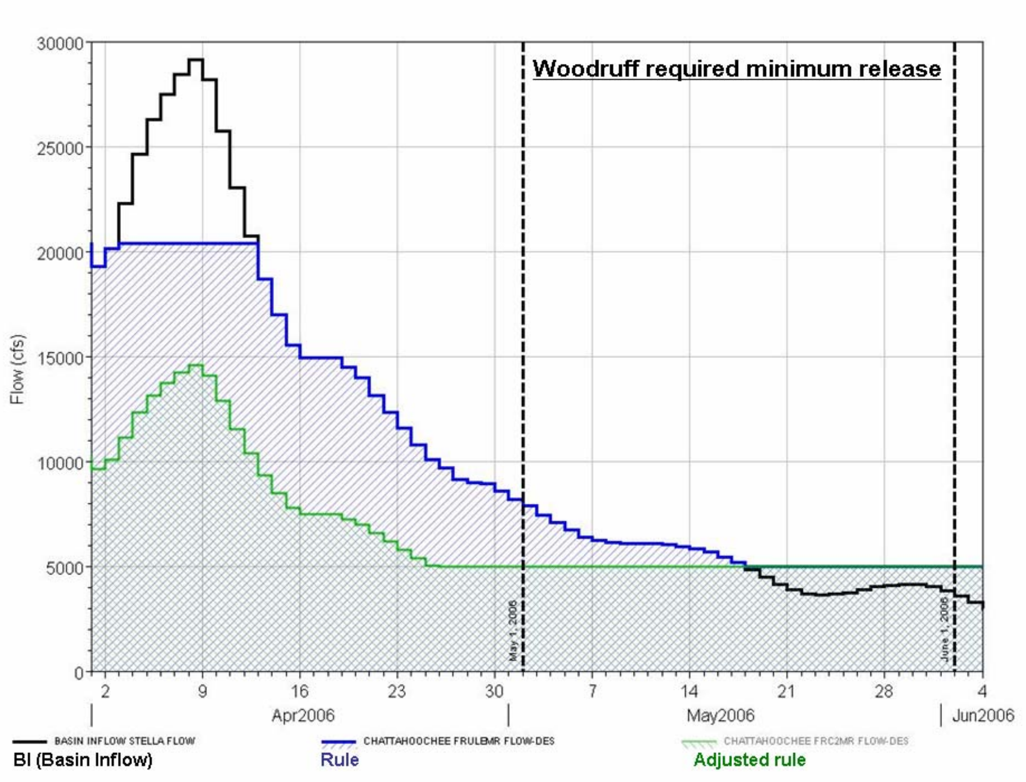

Figure 6: Example Type 2 rule correction–environmental target flows

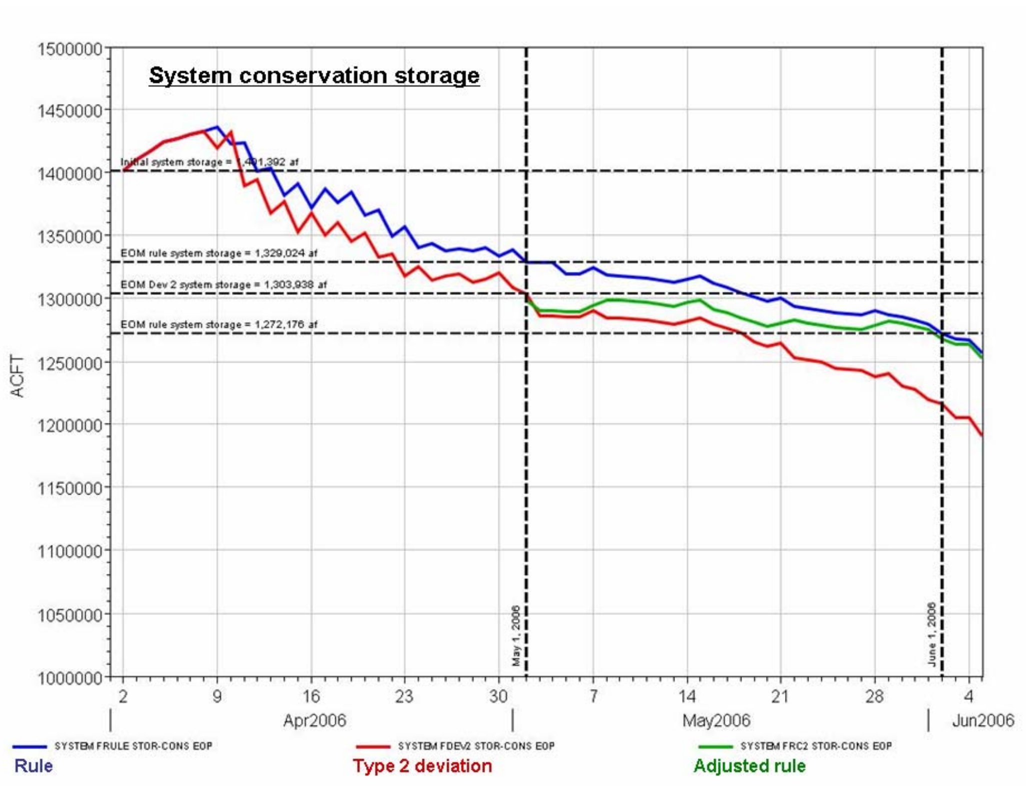

Figure 7: System storage recovery, Type 2 rule correction

Separable accounting may be necessary when storage under-utilization occurs as a consequence of both unintended and planned demand reductions. End-of-month system storage surplus accumulated as a result of natural low demand would be added to the initial system storage for the baseline rule and used as the basis tracking subsequent system storage deviations.

The example Type 3 deviation summarized in the following data involve a 30% reduction in Atlanta-area water demands and a 30% reduction in Flint River agricultural demand, both naturally-occurring. Because seasonal demands in this example were naturally low and not attributable to water conservation efforts, and because the end-of-month (EOM) positive system storage deviation is less than the 10,000-af hypothesized tolerance, no rule corrections or storage credits are required. Consequently EOM storage for the positive Type 3 deviation in April becomes the initial condition for May.

Storage account clearing: In most instances, all storage accounts are full when system conservation storage equals or exceeds levels defined by the baseline rule, or when system conservation storage is full. The following exceptions may apply:

- Conservation storage less than full in one or more system reservoirs
- System reservoirs significantly out of balance, i.e. not within the same zone with approximately equal percentages of storage remaining in each zone
- Conservation storage full or out of balance at one or more system reservoirs due to curtailing of releases to prevent downstream flooding
- Pre-releasing of conservation storage prior to anticipated flooding at one or more system reservoirs, causing reservoirs to be out of balance

Efficient system operation balancing storage among reservoirs of unequal size, drainage areas, and power generating capacity requires (1) rule curves (seasonal top of conservation pools) designed so that induced drawdown and refilling of reservoirs is conjunctive with seasonal demands on storage, and (2) guide curves within the conservation pools designed to equalize probabilities of refilling (to top of conservation pool) of system reservoirs within a period of time appropriate to volume of conservation storage relative to project inflows and at-site demands.

Special circumstances: Certain types of system operating rules and objectives may apply to competing uses of water in such a way that benefits of conservation by one use, whether intended or not, automatically accrue to one or more rival use – analogous to the free-rider effect of resource economics. Such a circumstance is disclosed by the Type 2 and Type 3 rule deviation examples previously provided. The environmental flow targets of the Type 2 deviation example increase in proportion to BI, which increases as a result of municipal, industrial and agricultural water conservation savings, used as the basis of the Type 3 deviation example. Thus municipal and agricultural water conservation is discouraged by the fact that most of the water saved simply adds to required flow deliveries downstream, diminishing or negating entirely benefits of sustainable storage utilization to the conserving purposes.

In these and similar circumstances where water demand by one purpose increases in relation to conservation by others, special storage-accounting procedures may be desirable to ensure against cross-subsidization among purposes. Likewise, conservation incentives may be a desirable component of effective basinwide management planning and could also promote consensus on the baseline rules.

VIRTUAL RULE-BASED STORAGE ACCOUNTING

Rule-based storage accounting may be implemented in river basins having little or no conservation storage. In such cases, one or more virtual reservoirs may be created at locations of interest within the basin where storage utilization may be tracked in relation to inflows, water withdrawals, wastewater returns, and interbasin transfers actually occurring upstream of the virtual reservoir site. Baseline rules for virtual reservoirs would define water demands but not releases or instream flow targets, unless water demands are also defined in relation to instream flows, e.g. withdrawals in excess of minimum instream flows.

SUMMARY AND CONCLUSIONS

The foregoing discussion is intended to guide the collaborative development and implementation of a framework for management and tracking of multiple competing, complementary, consumptive and non-consumptive demands on water and storage. Successful collaboration can produce an accounting system that promotes efficient and equitable distribution of the benefits, costs and risks of integrated river basin management (IRBM) to meet socioeconomic and environmental objectives. Basic elements of rule-based storage accounting are summarized as follows:

- Consensus-derived system baseline operating rules, priorities and constraints

- Policies and procedures for tracking and exchanging real or virtual storage among included purposes based on over- or under-utilization of storage in comparison to the baseline rule
- Procedures for formulation of temporary corrective rule adjustments to recover over-utilized storage, prevent cross-subsidization among included purposes, and avoid imposition of externalities on any purpose, whether included or not.

By giving all included purposes a stake in the management of the reservoir system, rule-based storage accounting provides an opportunity for participants in water management planning – and parties to water and environmental conflicts – to achieve consensus on water allocation formulas initially and to create a structure for participatory management and comprehensive water planning thereafter. As previously noted, rule-based storage accounting does not allocate water or storage, but helps to track and prevent unsustainable over-utilization by any purpose.

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