Surface Water Quantity Models

Progress Meeting Notes

May 3, 2016 – Teleconference

Attendees: **CDM Smith**: John Boyer, Tim Cox, Nina Caraway
SCDNR: Joe Gellici, Andy Wachob, Scott Harder, Alex Pellet, Bill Clendenin, Kerry Castle
DHEC: Leigh Anne Monroe, Rob Devlin, Wade Cantrell
Clemson: Katie Buckley
Technical Advisory Committee: Eddie Twilley, Ed Bruce, K.C. Price, Heather Nix, Mike Harrelson, Charles Wingard, Eric Kruger

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1. **Past and Future Stakeholder Meetings**
    a. 2nd Pee Dee Meeting Feedback
    - Ed Bruce commented that stakeholders might appreciate hearing more about how the models will be used during subsequent phases of the project, especially the regional/basin planning phase.
    b. 2nd Broad Meeting, Wed, May 18th
    - John Boyer noted that the second stakeholder meeting in the Broad will be held from 2:00 to 4:00 pm on Wed, May 18th [*at the Spartanburg Community College, Tyger River Campus in Duncan*].

2. **Update on UIFs and Model Development**
    a. Broad and Pee Dee
        i. Broad UIF partial response to comments (attached)
        - John Boyer indicated that CDM Smith has provided responses to most DNR comments on the Broad River Basin UIFs. Where UIFs impact model development and calibration, they have been addressed. Other UIFs will be addressed before finalizing the UIF dataset.
        ii. Draft Calibration Models submitted to DNR and DHEC

- John Boyer noted that Draft calibration models for both the Pee Dee and Broad river basins have been submitted to DNR and DHEC for review. The Draft Pee Dee River Basin Model Report has been updated and resubmitted, based on initial comments received from Alex Pellett/DNR. The Draft Broad River Basin Report is still being finalized and will be distributed between May 6th and 10th.

b. Edisto

   i. Final Model Report (attached)

   - John Boyer noted that the Edisto River Basin Model Report has been updated to reflect the final decision on headwater inputs, and the final calibration results have been included. A discussion has been added to the calibration section (Section 7) explaining the verification exercise that was conducted using Montmorenci gage data from 1940-1966, and the rationale for selecting the final reference gages.
   - Charles Wingard asked what had changed from the previous report to the final report. John Boyer indicated that Tables 6-1 and 6-2 were updated to reflect the final selection of reference gages; Section 7 was updated to summarize the calibration results; and Appendices A and B were updated to document the calibration results.
   - Charles Wingard questioned whether the available data was being used to the best extent possible. Bill Clendenin noted that the lack of USGS gage data in the Edisto was the most significant factor in increasing the uncertainty of model results in this basin, relative to other basins, where gage data is more prevalent. Additional gages are needed in the Edisto to better characterize the complex hydrology.
   - Charles Wingard noted his expectation that DNR will continue to update the model, as new gage data is acquired.
   - Alex Pellet indicated that DNR's decision to use the S. Fork Edisto at Denmark (EDO05) gage as the reference gage for most of the tributaries in the headwaters was based on the fact that it provided slightly more conservative low flow estimates in the upper part of the basin, and this was deemed more appropriate recognizing the uncertainty due to lack of gage data and the complex hydrology of the basin.
   - Scott Harder asked if CDM Smith had updated the model report to include a discussion regarding the final selection of reference gages. John Boyer indicated that a new subsection had been added to Section 7, which briefly discussed the verification exercise that was completed, and

the rationale for the final reference gage selection. Alex Pellett noted that he was in the process of summarizing DNR's decision regarding the reference gages. John Boyer suggested that he could incorporate that language into the report, and re-issue it.

- John Boyer noted that over the past several months, a number of alternative reference gage scenarios had been evaluated, and the selected scenario was originally presented and discussed during the December 9th, 2015 Progress Meeting. Eric Krueger asked if those slides could be redistributed to the TAC. Joe Gellici indicated that the slides are available on DNR's webpage, attached to the meeting minutes. John Boyer said he we would resend the file, or links to the file.

c. Saluda
   i. Finalizing Report

   - John Boyer noted that updates to the Final Saluda Report are still in progress.

d. Santee
   i. UIF Methodology Memorandum (attached)

   - John Boyer explained that, of the eight non-tidally influenced active and inactive USGS gages in the Santee River Basin, only five are potentially candidates for developing UIFs. The gages on the diversion canals are not candidates, since they do not represent locations where natural flow occurred. The inactive gage located where Lake Marion was constructed, is also not a candidate. John indicated that the UIF dataset will begin in 1941, which is when lakes Marion and Moultrie were constructed.
   - Wade Cantrell suggested that the gage just below Lake Moultrie may have some tidal influence in its record [*which was later determined to be correct*].

3. **SWAM Node and Reservoir Output Table Modifications** (example attached)
   - John Boyer explained that, based on DNR feedback, SWAM's node and reservoir output tables were modified to make it easier for the user to review and interpret the output. Columns of data that did had little or no meaning under riparian water rights law were removed. Reservoir output was revised so that inflow into each reservoir is displayed, and both regulated releases and outflow are displayed. Alex Pellet suggested that "outflow" could be further characterized so that the user does not misinterpret it as "total outflow". The label "Additional Outflow" was agreed to be used.

4. **Schedule Update** (attached to progress report)
   - John Boyer noted the updated schedule reflects the move of the 2nd Broad Stakeholder meeting to mid-May, and the delay of the Catawba-Wateree River Basin deliverables and 2nd meeting by approximately 1 month.

Memorandum

To: John, Boyer, CDM Smith

From: Scott Harder and Alex Pellet, SCDNR

Date: 1/28/16

CDM Smith Response in red – 5/2/2016

Re: Comments on draft UIFs for Tyger, Enoree, and Pacolet Subbasins

Pacolet:

1. BRD12:
    a. Assuming the Spartanburg Municipal Reservoir #1 was not in existence prior to 1960 (when Bowen was constructed) or if it has negligible impacts (considered run-of-river), then to develop the UIF at this gage, we would use the gage data from 1926 – 1960 with, of course, any other impairments considered (withdrawals and returns).
    CDM Smith Response: It has been updated such that it will be the unimpaired gage flow before 1960.
    b. Using BRD10 to estimate flows after 1960 is acceptable owing to the difficulties of unimpairing reservoir impacts. Please fully document reasons why this approach was taken in the final report.
    CDM Smith Response: Reasoning will be supplied in the final report, but to explain in the meantime, area proration of BRD10 appeared attractive as a substitution because:
        i. Lake Bowen is in series with Municipal Reservoir #1 and the former is controlled to maintain hydropower operations in the latter. Performing the UIF calculations using Bowen's available elevations and assuming Reservoir #1 as run-of-river resulted in less-than-ideal flows that likely would have required smoothing.
        ii. If the two reservoirs were going to be included in the UIF calculations, not only would Bowen's measured elevations would have required hindcasting, but also large gap filling, the worst of which would have been 1988-1995.
    c. QAQC worksheet: "reason to force the slope to zero for the Area Ratio? … to correct any bias" Does this comment in the QAQC worksheet refer to Cells D3 and E3 in the Area Ratio Worksheet [Area Ratio Worksheet Cell D3 & E3: "Modifier to make Slope of 1"; "0.965"]? Would the 'bias' be attributable to reservoir effects, specifically increased evaporation?
    CDM Smith Response: The QAQC worksheet should have said slope of one, not zero. The bias could be attributed to other effects as the correction indicates areas are a good predictor, but not perfect in explaining all the hydrology in this basin.

2. BRD14
    a. Using BRD10 to estimate flows at this gage is acceptable owing to the difficulties of unimpairing reservoir impacts from Lake Blalock. Please fully document reasons why this approach was taken in the final report.

CDM Smith Response: Reasoning will be supplied in the final report, but the primary motivation was that Lake Blalock underwent several years of construction including repairs and raising of the dam. In addition to issues arising from standard reservoir calculations, this would have resulted in several years of uncertainty caused by fluctuating stage-storage-elevation curves.

b. Prorating BRD10 UIF appears to correlate well with the unimpaired BRD14 during the overlapping period of record of reservoir elevation (2010-2013). Why does the comparison begin in April rather than January? Reservoir data does not extend prior to 2010, and therefore prorated BRD10 is used to represent unimpaired BRD14?
CDM Smith Response: Starting in April lies primarily with the consistency of gage flow records from BRD12. There is a large gap in flows from 11/9/2009 until 4/15/2010. After this date there are still gaps from BRD12, but are smaller in nature and were deleted from the area ratio comparison calculations.

c. Explanation of high flow and low flow adjustments? The prorated UIF gives 11% more flow than the gage… This appears to have an effect on BRD19, specifically from September to December 2012.
CDM Smith Response: While increase in flow may seem concerning, when comparing the calculated UIF from 2010-2013 to the gage flow of BRD14, the increase is even higher at 14%. To investigate these effects, explicitly-calculated UIFs and not area-prorated UIFs for BRD14 were carried through to BRD19. The higher flows in BRD19's 2012 period remained essentially unchanged with the overall increase between the two different calculations being only 1%. Given that there are major withdrawals upstream for Spartanburg water supply, it is not unusual to have higher UIFs than gage flows.

3. BRD15:
   a. We assume this gage is a candidate for gap filling/record extension for upstream gages from 1931-1960 in addition to BRD10.
   CDM Smith Response: Correct, it will be tested and likely used for filling early periods of record.

Tyger:

1. BRD35, 36, and 37 are impacted by a small reservoir, Berry's Pond, which had an active hydroelectric plant/mill from 1900 – 1968 (a website, http://www.pelzerinsulators.com/berryshoals.htm, describing the project said hydro operations ended in 1964, but the hydrograph for BRD36 suggest that operations ended in 1968). We are surprised that what appears to be a small reservoir (though adjacent small reservoir – Silver Lake may have been connected to Berry's Pond adding additional storage capacity) would cause the observed fluctuations. We are not sure what is causing all the flow fluctuations, but we believe that the data from BRD35, 36 and possibly 37 may be too impacted to be of much use at least on a daily basis. These gages should not be used for record extensions.

   In addition, the way dips in flow were handled (based on flows less than 70 cfs for BRD35) for gages on the South Tyger is not appropriate. This method add a considerable amount of water

to the river (approximately 8% of the period of record for the gage). These gages cannot be properly unimpaired owing to no reservoir information at Berry's Pond (or whatever other regulation may have occurred, so perhaps some type of smoothing similar to what was done on the Reedy River in the Saluda is warranted. However, we would avoid using these sites for record extensions or for reference gages as mentioned above. This method should not be used in any UIFS for any basin, except perhaps in those limited cases where negative flows need to be corrected.

CDM Smith Response: Thank you for providing additional context for the operational signal in these three gages. We agree their UIFs should not be used in the extension process. For BRD35, BRD36 and parts of BRD37 we implemented a technique similar to that used for the Reedy River. Given the period of the signal, 7-day smoothing was applied, unless the flow exceeds 1300 cfs anytime within a 9-day moving window, then the UIF remains as-is. This technique ensures no flattening of large peaks in the hydrograph without adding significant additional volume.

Enoree:

1. No comments on the Enoree as far as unimpaired flows are concerned. We do have a preliminary comment on record extensions. Area proration has been shown to be problematic at low flows (and perhaps other flow regimes) in this basin, in part owing to, large differences in land use in the upper part of the basin (more urbanized) and the middle to lower part (more rural or forested) of the basin. Just something to keep in mind if this hasn't been considered (may also affect calibration).
   CDM Smith Response: This will be kept in mind for the extension process as well as model calibration.

Memorandum

To: John Boyer, CDM Smith

From: SCDNR Hydrology Team

Date: 04/19/16

CDM Smith Initial Response in red – 5/2/2016

Re: Comments on the Broad River UIF dataset and memorandum

General:

1. On page 4, last bullet, gage 0219500 is on the Tyger River not the South Tyger River.

2. Parr Shoals was assumed run of river before elevations were gaged (1984), which may be a good assumption; however, there is evidence of impairment or regulation, especially in the earlier part of the record at BRD55 that is likely due to regulation at BRD24. This impairment gets transferred to other gages when BRD55 is used as an extension and leads to erroneous UIFS. We strongly recommend avoiding the use of BRD55 as an extension gage if possible.

3. BRD24 likely has a large degree of regulation that has not been corrected as well. Regulation is due to Neal Shoals reservoir, which was assumed run of river. However, there is evidence of regulation on a daily basis, especially in the early part of the record. This uncorrected regulation shows up in other hydrographs that use this gage when extending records. We recommend avoiding this gage if possible.

4. The method for hindcasting reservoir storage/elevations for Gaston Shoals seems to work quite well. Can this method be used to improve hindcasting in other reservoirs like Table Rock and North Saluda? Please verify that the time period used in the validation test for Gaston Shoals depicted in Figure 4.3 is not for the “training” period.

5. Decision plots and verification plots are often hard to read, which makes it difficult to determine if appropriate gages and methods were used. We recognize that CDM Smith is trying to sort through a great deal of data and data processing and trying to streamline the process, but please consider finding additional ways to present the data that makes it easier to evaluate the results. For example, we would like to consider how using MOVE.1 with and without the log transform for BRD01 and BRD02 would affect the results for a low flow year (2011 or 2012). This is difficult with the current output formats.

6. BRD52 and BRD58 are impacted by backwater effects from Parr Reservoir and Columbia Dam, respectively, and data should not be used (SCE&G has noted problems with BRD52, and are no longer funding it). These sites may have to be treated similar to an ungaged site. They should also, of course, not be used as a reference for an ungaged basin.

7. When gages are combined, list both gages and periods of record in table 5.1 for appropriate gages. If not already explicitly stated in the memorandum, please list those gages for which no UIFs were computed.

8. When there are noticeable changes in hydrograph dynamics from switching from one extension gage to another or if an extra extension gage is used to cover a few years of data when another extension gage already being used could have covered it, try to limit the number of gages being used. This would need to be done on a case by case basis and only if the integrity of the UIF is not impacted much. See BRD18, for example, (though we don't have an issue with this particular part of the hydrograph necessarily), BRD40 is used to fill in a few gaps in place of BRD12, when BRD12 could have continued to be used.

9. Please explain (or perhaps explain again) how the R programs are used to select candidate extension gages. Our understanding, is that at least in part, the Pearson and Kendall correlation coefficients are used to pick the top candidate gages. However, we want to be sure that this process does not exclude other potential gages that may have great value or applicability, but are discarded because the correlation coefficients may be slightly less.

   CDM Smith Response: The first code, "FindFills.r", calculates and plots correlations only for gages which offer additional years of extension. For a basin like the Broad with many gages, this serves as simply a filtering step to help eliminate gages, though initially appearing applicable, would have no use in the extension process. Then given this initial filtering, a list of candidates can be tested and examined in the following codes.

Comments/suggestions on individual gages:

Buffalo Creek

Regression was used for managed flows for 2009-2013 period. What actually was "regressed"?

BRD01:

1. BRD01 (Broad River near Blacksburg) for the period of 2009-2013 uses BRD10 (North Pacolet River at Fingerville) to compute UIFS instead of using the Broad River near Boiling Springs, NC or just the Blacksburg gage itself. We assume that since CDM is not required to consider unimpairments in NC, that it was not possible to simply unimpair the Blacksburg gage? We may question the use of using the North Pacolet gage despite the good correlation.

2. Why not simply use the raw Blacksburg data for managed flow from 2009-2013, instead of using the regression with the Boiling Springs gage?

   CDM Smith Response: Raw Blacksburg data is still being used. The regressed Boiling Springs is need for upstream managed flows.

3. Are "managed flows" the output from the baseline OASIS model? The methodology TM, we think, states this, but we want clarification on what is meant by "managed flows". We may

desire a little more background on the baseline OASIS model and what NC means by "baseline".

4. BRD01 time series graph should denote BRD10 (with area proration) was used for 2009-2013.

   CDM Smith Response: Area-prorated BRD10 was not used to replace 2009-2013 BRD01 flows. It was used to estimate corresponding unimpaired flows for OASIS output, which ended in 2009.

5. Extension used BRD02 with a hybrid approach: MOVE.1 with no log transform (though there are only 3-4 years of overlapping data) and area ratio for flow less than 251 cfs. This may be ok, but unless there is no good reason to not use log transform, then this should be the default. Also, how was 251 cfs determined as the threshold flow?

BRD02:

1. Period of record for gage listed in Table 5.1 is incomplete.

BRD03:

1. We recommend MOVE.1 with the log transform be used with BRD02.

   CDM Smith Response: This has been updated.

BRD04:

1. BRD24 appears to be impacted by regulation at Neals Shoals that has not been removed from its UIF. The signature of this regulation shows up in other gages when BRD24 is used as a reference, such as in BRD04. There is a discontinuity in flow behavior in the 1940s and 1950s and the rest of the period of record which is likely due to using BRD24.

2. SLD14 as an extension gage is suspect owing to how far away it is.

3. Overall, verification plots don't look great.

4. Consider BRD02 in place of BRD24 or SLD14 similar to what was done for BRD05.

   CDM Smith Response: BRD24 and SLD14 have been removed and BRD02 has been used instead.

BRD05

1. Workbook is missing.

   CDM Smith Response: This gage did not need any unimpairment calculations, only extension, thus its basin and flow information resides in UIF_USGS_Headwaters.xlsx with others of this type. Though not requested, removed SLD14 given comments for BRD04.

BRD06:

1. Avoid using BRD24.

   CDM Smith Response: This has been updated.

BRD07:

1. Avoid using BRD24 and SLD14. Consider using BRD02 and/or BRD10.

2. BRD43 has less than 2 years of overlapping data. Is MOVE appropriate for less than 2 years of data? 2002 drought is also muted.

   CDM Smith Response: BRD24, SLD14, and BRD43 have been removed and BRD02 added.

BRD08:

1. Was BRD04 considered as an extension gage? It is very close to BRD08.

   CDM Smith Response: BRD04 does not have any years of overlap and can only be tested by examining how it looks in the final timeseries. However, given their similarities and how the final timeseries appears, BRD04 has now been added.

2. Avoid using BRD24 and SLD14.

   CDM Smith Response: These have been removed.

BRD12:

1. BRD12 final UIF plot and description in table 5.1 doesn't seem to match the extensions methods discussed on pages 3-4 (section 2.0). Shouldn't BRD10 be listed as an extension reference gage from 1960-2013?

2. Also period of record for BRD12 is 1929 to 2013 (not 1996 as listed in table 5.1) with a few apparent data gaps. Why is MOVE.1 used to fill these data gaps with BRD10 when rest of post 1960 period according to section 2.0 uses area proration or a regression with BRD10. Why not simply continue to use area proration?

3. "Slope of regression adjustment" for BRD12 (and others?) should be better documented. For example, describe methodology fully with appropriate equation(s) (similar to MOVE.1).

BRD14:

1. Please explain "slope of regression adjustment" for both low and high flows in more detail and include in write up of methodology. What was the thresholds for low, high flows? We did not see where this was documented in the BRD14 workbook (if it is documented, please let us know where).

2. Similar to BRD12, is not the use of an adjusted area proration really an extension method and not an unimpairment method (at least in the same sense other gages are

"unimpaired")? If so, then table 5.1 and extended timeseries plot should include this period as an extension.

3. If BRD10 was used to estimate BRD14 flows for 1993-2013, why use BRD12 with MOVE.1 to extend back to 1929? Why not be consistent and use BRD10 and the adjusted area proration method back to 1929 or at least back to 1960, after which BRD12 data is based on BRD10 flows anyway?

BRD15

1. Gage data likely affected to some degree by Clifton Mills in the 1940s and 1950s, though we are not sure if its worth trying to correct, since time period will likely not be part of calibration period.

   CDM Smith Response: BRD15 has no effect on other UIFs either through extension or ungaged estimation.

BRD18

1. Period or record listed in table 5.1 should include period for BRD17 (gage it was combined with)

2. Since BRD12, post BD10, is based on an area prorated a BRD10, shouldn't gages for extension rely more on BRD10 than BRD12 post 1960? This may be true for other gage extensions as well.

   CDM Smith Response: Most of the extension required that would use BRD12 or BRD10 is for the earlier record anyway.

3. Dry period from 1999-2002 is muted heavily. Based on frequency plot and verification plot (though do not see BRD46 with transform on the verification plot), using BRD46 with no transform does not seem appropriate. We recommend trying BRD46 with the transform.

4. Why was BRD16 not considered as a reference gage since it's on the same stream?

   CDM Smith Response: BRD46 has been removed and BRD16 is now used.

BRD19

1. Overlapping period of record appears to be too small to use MOVE.1 for this site. Even if MOVE.1 is chosen, the log transform appears to be better than no transform and we would recommend its use.

   CDM Smith Response: Changed to log transform.

2. This site may warrant a more sophisticated extension owing to its importance of being near the confluence with the Broad.

CDM Smith Response: This gage has no influence in the model, is neither used to extend others nor its final timeseries used for ungaged estimation.

BRD20

1. Avoid using BRD24 if possible.

   CDM Smith Response: BRD24 has been removed.

BRD21 and BRD22

1. Avoid using BRD24 if possible, impairment still in the data.

   CDM Smith Response: BRD24 has been removed.

BRD23

1. Consider another gage in place of BRD55 (drainage area much larger and some evidence of impairment in BRD55). In addition, BRD55 with the transform appears superior to BRD55 with no transform.

   CDM Smith Response: BRD26 is now being used as much as possible in the early record. Removing BRD55 eliminates most early record options, but prorated BRD49 appears sufficient in the final timeseries.

BRD31

1. Using BRD30 with no transform appears to mute recent droughts (2002, 2007-2008, 211-2012). Reconsider using with transform or test with other candidate gages.

   CDM Smith Response: Given lack of overlap, there are not many other options to test. Despite diagnostics, transform is now used with BRD30 for sake of low flows.

BRD34

1. Was BRD26 considered as a reference gage for 1970s and 1980s period? BRD26 may be better match than BRD10 for these periods.

   CDM Smith Response: BRD26 does not have an overlapping period for testing. But, it does appear to fit well in the final timeseries.

BRD35

1. Using MOVE.1 on smoothed data is questionable.

   CDM Smith Response: Agree if smoothed data was being used to extend a non-smoothed gage, or vice versa. But, both BRD35 and BRD36 have been smoothed using similar methods and for the same period of time.

2. Was BRD26 tested for 1970s and 1980s as an extension gage

CDM Smith Response: Was re-tested and BRD26 has been added.

3. For 1990s, were any of the Enoree gages checked as an extension?

   CDM Smith Response: Only BRD49 offered any overlapping record to test.

4. Was BRD33 considered for 2001 to 2013? This gage is on the South Tyger, while BRD30 is on the Middle Tyger.

   CDM Smith Response: No overlap to test.

BRD36

1. Using MOVE.1 on smoothed data is questionable.
2. Was BRD26 considered for the 1970s and 1980s?
3. For 1990s through 2013, were any of the Enoree gages checked as an extension?
4. Was BRD33 considered for 2001 to 2013? This gage is on the South Tyger, while BRD30 is on the Middle Tyger.

   CDM Smith Response: Same responses as with BRD35, except that BRD26 in this case had been considered and was already being used.

BRD37

1. Reconsider using BRD42 through 2013 in place of BRD30. BRD30 may overestimate low flow periods.

BRD41:

1. Hydrograph dynamics at low flows are noticeably different than at the upstream site at BRD40.
2. We strongly recommend using the log transform here with, if necessary, a high flow correction.

   CDM Smith Response: Changed to log transform.

3. Was BRD40 considered as a reference gage, after all, it's on the same stream?

   CDM Smith Response: While BRD40 does have an overlapping record to test, it does not offer any years of extension.

BRD42:

1. The apparent impairment in BRD24 (that has not been accounted for) prior to around 1960, strongly suggests that BRD24 should not be used prior to 1960. We strongly recommend finding another extension gage for this period.

2. BRD55 may have impairment as well that wasn't accounted for so may need to avoid using prior to 1940.

   CDM Smith Response: Reference changed to BRD49.

BRD43:

1. Was BRD50 checked as a reference gage? Was area proration tested?

   CDM Smith Response: Had been checked in a previous iteration, was re-tested. Does not have desirable correlations or diagnostic plots.

BRD44:

1. BRD18 doesn't appear to do well at low flow range based on frequency plots. Consider replacing with another gage, such as BRD48, if appropriate.

   CDM Smith Response: After using BRD46, other good candidates on the Enoree systemlike BRD43, BRD47 or BRD48 do not offer additional years of extension. However BRD16 does seem a suitable replacement.

BRD47:

1. BRD49 with area ratio is used from 1929-1977, but there is no way to verify whether area ratio works in this case, since there is no overlapping period of record. We would like more justification as to why area ratio method was implemented here as opposed to using MOVE with longer period of record gages (BRD10 for example).

   CDM Smith Response: Though there is no overlap to test, BRD49 appears suitable in the final timeseries.

BRD53:

1. We don't think there are really any other options here, but unaccounted for impairment in BRD55 (in part cause by unaccounted for impairment in BRD24) affects UIF here, especially prior to 1960.

   CDM Smith Response: BRD55 has been removed.

BRD54:

1. BRD55 has unaccounted for impairments and that, possibly combined with using MOVE with no transform, leads to more frequent and severe low flow periods in the 1930s through the 1950s – generally more frequent than the recent severe droughts. This is unlikely. Is there not a way to improve the unimpairment of BRD55?

   CDM Smith Response: BRD55 has been removed.

BRD55:

1. See BRD54

BRD57:

1. Using MOVE with the log transform for BRD49 and BRD50, after reviewing the decision and verification plots, appears to be a much better approach than not using the transform. Frequency plots are far superior with the transform than without for most of the exceedance probability range. We strongly recommend using the log transform, even at the expense of some error in the real high flows.

   CDM Smith Response: Updated to log transform.

Technical Memorandum

To: *South Carolina Department of Natural Resources (DNR)*
South Carolina Department of Health and Environmental Control (DHEC)

From: *CDM Smith*

Date: *May 2, 2016*

Subject: *Unimpaired Flow Development*
Santee River Basin, South Carolina

1.0 Background and Objectives for Unimpaired Flows

Unimpaired Flow (UIF) describes the natural hydrology of a river basin. UIFs quantify streamflows throughout a river basin in the absence of human intervention in the river channel, such as storage, withdrawals, discharges, and return flows. From this basis, modeling and decision making can be compared with pristine conditions.

This memorandum identifies the active and inactive flow gages the Santee River basin and provides recommendations on where UIF development may occur.

2.0 Overview of the Santee Basin USGS Gages

Eighteen Unites States Geological Survey (USGS) gaging stations monitor streamflow in the Santee River Basin. Of these, only eight are not located in tidally influenced areas, including three on the Santee River, one on the Cooper River, two on tributary streams, and two on diversion canals. Only four of the non-tidally influenced gages are currently active.

An overview map of the USGS streamflow gages in the Santee River Basin are shown in **Figure 1.** **Figure 2** depicts the length and timing of records available for the non-tidally influenced USGS gages in the Santee River basin.

Figure 1. Santee River Basin USGS Streamflow Gages (with project IDs)

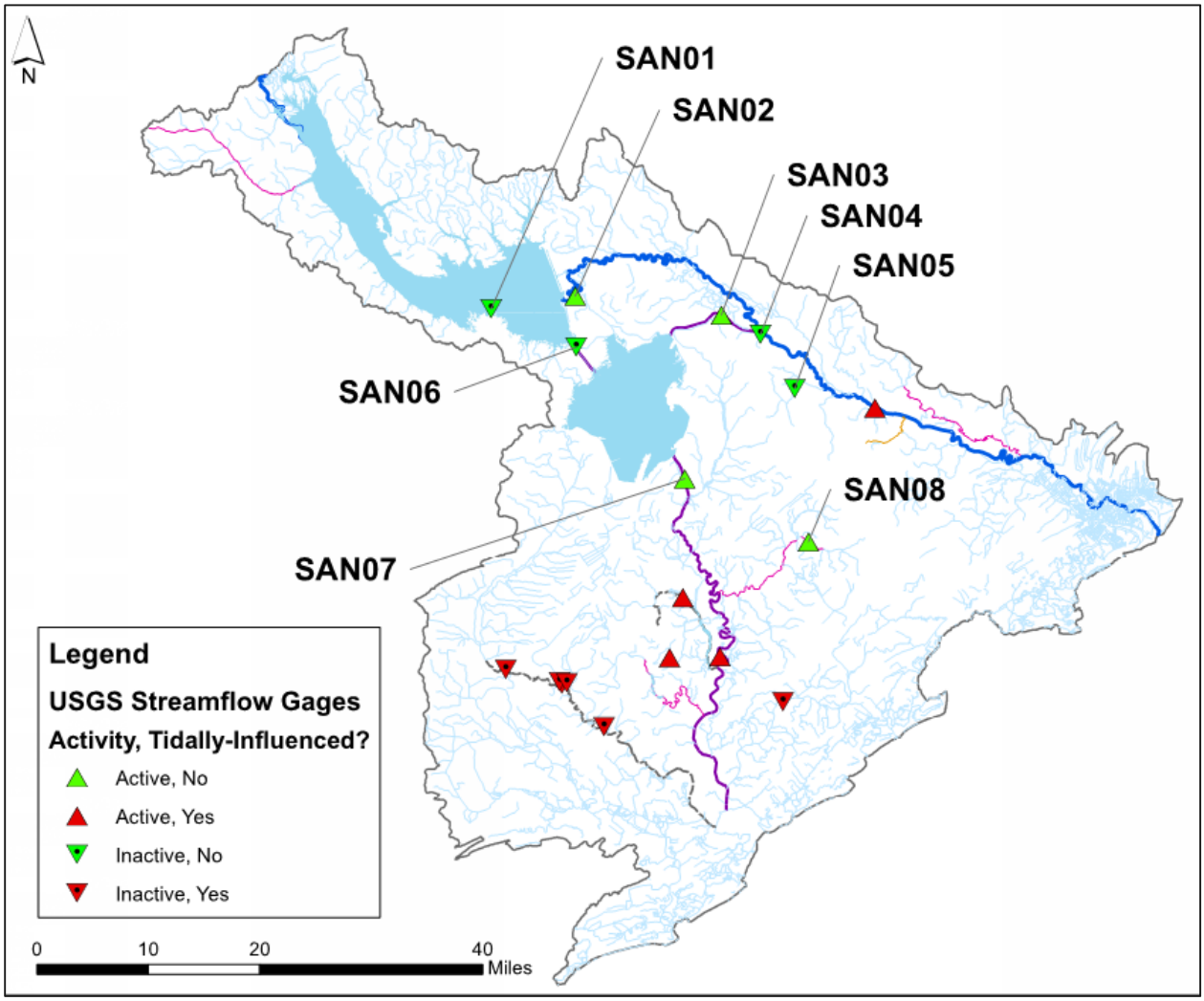
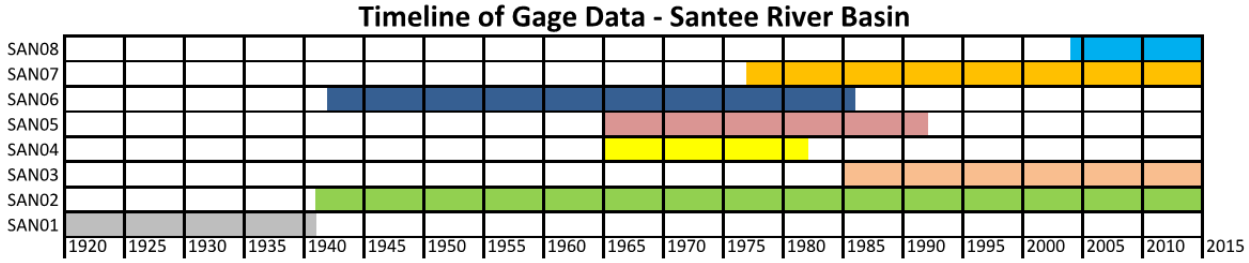


Figure 2. Period of record for USGS gages in the Santee Basin



3.0 Recommendations for UIF Development

The eight non-tidally influenced USGS gages are candidates for UIF development. A detailed explanation for each of these gages is listed below:

SAN01 (USGS 0217000): This gage has been inactive since 1941, since the construction of Lake Marion. Its original location now places it in the middle of Lake Marion, six miles upstream of the current dam. UIF development at this gage is not recommended since it is now within Lake Marion. However, the hydrologic patterns of SAN01 can still serve as validation tools for the SAN02 UIFs for comparing seasonal fluctuation, annual average flow, and low flow statistics.

SAN02 (USGS 02171500): This active gage (1941-2015) is located just downstream of Lake Marion dam on the Santee River. This is the replacement gage to SAN01, becoming active the year SAN01 became inactive. Although the unimpairment of Lake Marion and its multiple diversion canals may be complex, SAN02 is a candidate for UIF development. SAN02 is recommended as the primary gage for this basin's period of record.

SAN03 (USGS 02171645): This gage is located on the rediversion canal from Lake Moultrie to the Santee River. UIF development is not recommended since it does not reflect a location where natural (unimpaired) flow once occurred.

SAN04 (USGS 02171650): This inactive gage (1966-1982) is located on the Santee River downstream of a confluence with the rediversion canal from Lake Moultrie. This gage is a candidate for UIF development.

SAN05 (USGS 02171580): This inactive gage (1966-1992) is located on Wedboo Creek, tributary to the Santee River. This gage is a candidate for UIF development.

SAN06 (USGS 02170500): This gage is located on the diversion canal from Lake Marion to Lake Moultrie. UIF development is not recommended since it does not reflect a location where natural (unimpaired) flow once occurred.

SAN07 (USGS 02172002): This gage is located on the Cooper River just below the outlet from Lake Moultrie. Unimpairment of this gage requires removing the effects of Lake Moultrie and the input of flow from Lake Marion. This gage is a candidate for UIF development.

SAN08 (USGS 02172035): This gage is maintained and used by the Francis Marion National Forest parks service. This gage is a candidate for UIF development.

4.0 Summary

Five of the eight USGS gaging stations are candidates for UIF development. The three exceptions are SAN01, which is currently inundated, and the two diversion canals, SAN03 and SAN06. Although SAN01 is not a candidate for UIF development, its original record will still be used to check patterns in the UIF for SAN02. UIF development is not recommended for gages located on diversion canals since they do not reflect a location where natural (unimpaired) flow once occurred.