OFFICE OF ENVIRONMENT
AND HERITAGE

REVIEW OF ARR DESIGN INPUTS FOR NSW

FINAL REPORT

FEBRUARY 2019

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Project Review of ARR Design Inputs for NSW	**Project Number** 118014
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Date 11 February 2019	**Verified by** MKB

Revision	Description	Distribution	Date
4	Final Report	OEH/ARR Datahub	January 2019
3	Draft Report – Stage 2	OEH	December 2018
2	Final Draft Report	OEH	August 2018
1	Draft Report	OEH	June 2018

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EXECUTIVE SUMMARY

Background

This study was funded by the NSW Office of Environment and Heritage (OEH) to address concerns by practitioners of the underestimation bias in the standard ARR 2016 method for deriving design events and to develop advice on any changes needed in the methods or parameters used for flood estimation to address this bias in NSW.

Method

Bias in the ARR 2016 method were investigated by undertaking both the standard ARR 2016 method for deriving design events and At-site Flood Frequency Analysis (FFA). Where a good rating curve and a long flood record is present then FFA provides the most reliable flood estimate as it directly incorporates all of the catchment characteristics. For this reason, all other flood estimations techniques are parameterised, calibrated or validated to FFA. By comparing design event results to flood frequency estimates an understanding of the bias can be determined.
The standard ARR 2016 method described in this report was used to calculate the various design event quantiles using the ARR Data Hub values and BoM IFD. It automatically extracted temporal patterns, initial and continuing losses, pre-burst rainfalls and areal reduction factors from the ARR Data Hub (Babister et al. 2016) and Bureau of Meteorology (BoM) design rainfalls were obtained automatically from the BoM website.

FFA is a standard validation technique for rainfall-based design flood estimation and is the basis behind most methods of estimating flood frequency. Australian Rainfall and Runoff Revision Project 5: Regional Flood Methods (Rahman et al. 2015) carried out At-site FFA at numerous water level gauges across the country as part of the derivation of the Regional Flood Frequency Estimation (RFFE) method.

The 165 gauges in Figure 1 were chosen for this study. These:

- Include gauges used in ARR Revision Project 5 to assist in the quality controlling of the At-site FFA
- Include gauges where the highest quality of At-site FFA was expected to be achieved
- Provide the largest possible coverage across NSW.
- Provide catchment sizes ranging from 1.95km^2 up to a maximum of 2000 km^2

Comparison of the At-Site FFA and the standard ARR 2016 method was undertaken at all locations. These highlight a strong trend of the standard ARR 2016 method underestimating the At-site FFA. In addition, testing of estimates of burst initial loss derived by subtracting the median pre-burst from the storm initial loss showed a significant overestimation of burst initial loss due to the skew nature of the pre-burst distribution.

Investigations were undertaken to determine if it is possible to compensate for any potential bias in the ARR 2016 inputs and methods by:

- modifying the initial and continuing loss values for a given catchment so that the Standard ARR 2016 method matches the At-site FFA.
- Using alternate methods that account for the full distribution of pre-burst rainfall.

Conclusions

This work has shown that there is a considerable underestimation bias in the standard ARR 2016 method in NSW. This underestimation needs to be addressed to ensure that flood behaviour and impacts are not under-estimated and new waterway infrastructure not undersized leading to increased exposure of the community to flood risk.

Recommendations

To address the issue, it is recommended that:

- The ARR Datahub be updated to incorporate NSW specific data consistent with this report.
- Practitioners use the following hierarchical approach to loss selection until further research and associated more definitive advice is made available:
    1. Use the average of calibration losses from the actual study if available
    2. Use the average calibration losses from other studies in the catchment if available and appropriate for the study.
    3. Use the average calibration losses from other studies in the similar adjacent catchments if available and appropriate for the study.
    4. Use the FFA-Reconciled Losses from Figure 20, Figure 21 and Table C3 (and available through the ARR Data Hub) for nearby similar sites. Caution should be applied when using FFA-Reconciled initial loss as it may not be well calibrated with the catchment size chosen in this study. Additional scrutiny should be applied to initial loss values for catchments of 100km^2 or less.
    5. Until revised losses are generated using a better predictor equation (discussed below) use raw ARR Data Hub continuing losses with a multiplication factor of 0.4. Use the unmodified ARR Data Hub initial losses and apply additional scrutiny to them for catchment areas of 100km^2 or less to ensure they are representative for the catchment.

Where good local initial loss data is not available (Cases 4 and 5) the probability neutral burst initial loss values calculated in this study should be used in all instances unless a detailed Monte Carlo assessment of pre-burst and losses has been carried out. Arrangements have been made so that these values can be obtained from the ARR Data Hub. For storm initial losses obtained using items 1-3 in the above hierarchy, burst initial losses should be adjusted using the following equation.

$$IL_{B-chosen} = IL_{storm-chosen} \times \frac{IL_{B-ARR}}{IL_{storm-ARR}}$$

- further work be undertaken using the data set from this study to assess whether a better predictor equation can be found and to validate any relationships found using a leave one out analysis.

1. INTRODUCTION

The NSW Office of Environment and Heritage (OEH) provides technical, financial and policy support through the NSW Floodplain Management Program to local councils to understand and manage their flood risk through the floodplain risk management process outlined in the NSW Floodplain Development Manual. As part of this role OEH funded this study to address concerns by practitioners of under-estimation bias in the standard ARR 2016 method and to give advice on any changes needed in the methods or parameters used for flood estimation to address any bias found in NSW.

Rainfall based flood frequency analysis, commonly referred to as the design event method has been used extensively in Australia to obtain flood frequency estimates in ungauged catchments. Australian Rainfall and Runoff (ARR 2016) (Ball et. al, 2016) provides detailed guidelines for flood investigations using the design event method at any location in Australia. This method uses the following design inputs:

- Initial and continuing losses,
- Temporal patterns for rainfall,
- Pre-burst rainfalls,
- Design rainfalls (Intensity-Frequency-Duration, IFDs), and
- Areal reduction factors (ARFs).

Each of these inputs has potential errors that could contribute to the over or underestimation of design flood quantiles. It is also possible that these errors could compound and result in significant over or underestimation. The standard ARR 2016 method described in this report was used to calculate the various design event quantiles using the ARR Data Hub values and BoM IFD. It automatically extracted temporal patterns, initial and continuing losses, pre-burst rainfalls and areal reduction factors from the ARR Data Hub (Babister et al. 2016) and Bureau of Meteorology (BoM) design rainfalls were obtained automatically from the BoM website.

In comparison, At-site flood frequency analysis (At-site FFA) generates design flood quantiles by fitting a probability distribution to an annual maximum series (AMS) of flow estimates at a water level gauge. This makes it ideal for independent validation for design event methods as the only potential source of bias lies in the rating curve that converts water level recordings to flow estimates and the assumption that the chosen probability distribution is representative of the dataset. For this reason, all other flood estimations techniques are parameterised, calibrated or validated to FFA. It is the basis behind most methods of estimating flood frequency. Australian Rainfall and Runoff Revision Project 5: Regional Flood Methods (Rahman et al. 2015) carried out At-site FFA at numerous water level gauges across the country as part of the derivation of the Regional Flood Frequency Estimation method (RFFE).

This study examined the overall bias in the ARR 2016 method by comparing the result of both the standard ARR 2016 method and At-site FFA results for select gauged catchments in NSW. The 165 gauges in Figure 1 were chosen for this study. These:

- Include gauges used in Project 5 to assist in the quality controlling of the At-site FFA
- Include gauges where the highest quality of At-site FFA was expected to be achieved

- Provide the largest possible coverage across NSW.
- Provide catchment sizes ranging from 1.95km^2 up to a maximum of 2000 km^2
- Have an even distribution of catchment area and length of record, shown in Figure 2

In addition, testing the AEP neutrality (will not affect the AEP of the input rainfall) of pre-burst and the assumption that using the median pre-burst rainfall is representative of the pre-burst rainfall distribution was undertaken in this study.

This method was originally tested on 48 catchments along the NSW coast, and was expanded to include an additional 117 catchments across NSW in the second stage of the study based on the recommendations from the first stage. Some aspects of the study undertaken on the original 48 test catchments were not repeated for the final set, as the findings were not expected to change and did not influence the final results.

When matching a flood model to an observed event, the initial continuing loss model to some extent represents the theoretical absorption of rainfall by soils, but also is a simple way for compensating for input and model errors. Historically the modification of losses has been used as a way of compensating for the compounding bias in design event methods. When using losses this way they are really being used as an error reconciliation or closure term.

Should bias be found in the ARR 2016 design event method, the potential for modification of the ARR 2016 losses to compensate will be determined as part of this study. In addition, if the use of median pre-burst rainfall is not considered representative in NSW then a recommendation will be made for an alternate method.

ARR 2016 allows and in fact encourages designers to adopt alternative design inputs where they better fit local data (Ball et. al, 2016) and are available.

> "*Therefore, where circumstances warrant, designers have a duty to use other procedures and design information more appropriate for their design flood problem*"
> (Book 1 Chapter 1 ARR 2016)

2. AVAILABLE DATA AND BACKGROUND

2.1. RFFE and Project 5 estimates

RFFE is a technique developed as part of Australian Rainfall and Runoff Revision Project 5: Regional Flood Methods that estimates peak design flood estimates at any location within Australia given the catchment centroid, outlet and total area (Rahman et al. 2015). It is based on 853 gauged catchments around Australia that are divided into regions based on geography and data quality. All the gauges in this study are within the high-quality data “East Coast” RFFE region. Within the high-quality regions, estimates of flow are based on Bayesian regression of historical flow data from multiple gauges.

Due to the regional nature of this approach it has many limitations. Catchments that do not represent the natural drainage characteristics of the topography, such as urbanised areas, areas of significant land clearing, or areas influenced by dams will not be accurately estimated by RFFE. Also, due to limitations in the number of gauges, very large (> 1,000 km^2) and very small (<0.5km^2) catchments are not accurately estimated by RFFE.

2.2. Water Level Data

Time series water level data for each gauge was obtained from the DPI Water Real Time Data website (DPI Water, 2018) now available via Water NSW. The data was received as date-time and level pairs for all recorded values at each gauge included in the study. These levels were used to infer flow using the rating curve (see Section 2.3) at each gauge. This was then used in the determination of the annual maximum series (AMS) (see Section 3.1).

2.3. PINEENA Rating Curves and Gaugings

PINNEENA is a resource provided by the NSW Government that archives large amounts of historical water data collected by various state government agencies. The dataset contains the rating gaugings and derived rating curves at each gauge including those examined in this study.

The rating gaugings describe corresponding level readings at the water level gauge with flow measurements taken at the same instant, and from many readings a “rating curve” is fit through the data defining a relationship between level and flow at that gauge. The rating curves applicable to the relevant periods were used to derive flows from instantaneous water level readings at each gauge of interest that was used to derive the AMS (see Section 3.1). For gauges that have changed characteristics over their record, the use of a single rating curve may result in errors in flow estimates. When alternative more accurate rating curves were known to exist they were applied.

2.4. BoM Geofabric

Sub-catchments for each of the 165 test catchments were delineated using version 2 of the BoM Geofabric.

The BoM Geofabric provides a digital database of surface hydrologic features and their spatial relationships. Hydrological catchment boundaries, routing behaviour and stream lengths are derived from the SRTM 9 second DEM (Geoscience Australia, 2008) in combination with the GA ANUDEM Streams (Hutchinson, 2011). This data allows for the derivation of sub-catchments for input into the hydrological model without the need to process DEM data for areas upstream of the gauges of interest. The current work used version 2 of the BoM Geofabric, which will be replaced by version 3 in the near future. Version 3 is based on a finer DEM.

2.5. ARR Data Hub

Many of the design inputs are available for extraction on the ARR Data Hub (Babister et al. 2016). A shapefile was loaded onto the website and the design inputs downloaded as a text file. The ARR Data Hub extracts the components of this output for the input shapefile from many datasets. This is described in The Australian Rainfall and Runoff Data Hub (Babister et al. 2016). This section gives some context to these datasets.

2.5.1. Losses

Initial and continuing loss grids were derived for all of Australia as part of ARR 2016 and are the dataset associated with the loss values that can be obtained from the ARR Data Hub. These grids were derived by determining initial and continuing loss values for a number of events at 38 test catchments across the country, 3 of which are on the NSW coastal strip (Hill et al. 2016). The median values were taken from the initial and continuing loss sets for the test catchments and a multiple linear regression was fit to this data using parameters such as:

- meanPET – the mean annual potential evapotranspiration
- SOLPAWHC – the average plant available water holding capacity across the catchment
- KS_{sat} – the saturated hydraulic conductivity of shallow soil layer
- S0max – the maximum storage of the soil layer

These predictors come from a range of sources including AWRA-L (Bureau of Meteorology, 2018) inputs, the Australian Atlas of Soils and Australian Rainfall and Runoff Revision Project 6: Loss Models for Catchment Simulation: Phase 4 Analysis of Rural Catchments (Hill et al. 2016). These regressions do a reasonably good job of estimating the median losses of the catchments within the region, yielding R^2 values of 0.68 and 0.92 for initial and continuing loss respectively in the region applicable to this study. However, the analysis used data limited from are only 3 catchments in coastal NSW and there was a high level of uncertainty around the estimates of regression parameters in many areas. An assessment by RHELM (2018) found that some of the soil types used in the Wollongong area were incorrectly classified.

This results in there being a high likelihood that these loss estimates could be inaccurate in some areas. Multiple linear regressions can overfit the input data and be a poor predictor of values elsewhere, especially when a wide range of regression parameters are considered as they were for ARR 2016. Therefore, the standard ARR 2016 losses available through the ARR Data Hub are not reliable representations of the true losses everywhere.

2.5.2. Pre-burst Rainfalls

Pre-burst rainfall distributions were created at points across the entire country and converted to grids as part of ARR 2016. The distributions were determined at the points by finding the 40 closest rainfall events from the events database (WMAwater, 2015a) to target durations and AEPs using Equation 1.

$$c_{tot} = \left|\frac{IFD_{local} - IFD_{candidate}}{IFD_{candidate}}\right| + |NormInv(AEP_{local}) - NormInv(AEP_{candidate})| + \left(\frac{distance\ km}{500}\right)^2 \qquad (1)$$

While this generally provides a good balance of chosen events, in data sparse areas or areas with sharp changes in pre-burst characteristics, it is possibly that the pool of events is not appropriately representing the values at the target site. In some situations, floods can be produced by a combination of storm volume and high rainfall intensities in the critical burst. When a catchment is particularly sensitive to this then the assumption that the median pre-burst is appropriate for use may be invalid. This is investigated further in Section 7.

2.5.3. Point Temporal Patterns

To select the point temporal pattern sets that are recommended for use by ARR at catchment sizes smaller than 75km^2, Australia was split into temporal pattern regions. From these regions 10 events were selected from the events database (WMAwater, 2015b) that did not contain any significant embedded bursts and were within the desired annual exceedance probability (AEP) range.

It is possible that the temporal pattern set used is not as representative of the rainfall behaviour the target site experiences, although the use of 10 temporal patterns should generally represent enough variability to be applicable to the target site. The presence of embedded bursts, which could lead to peak flow overestimation, is possible as the method moves one pattern to a location with different IFDs embedded bursts can be introduced.

Where the target site is in the vicinity of the boundary of the temporal pattern regions ARR recommends careful consideration should be given to examining patterns in the bins of adjoining regions.

2.5.4. Areal Temporal Patterns

Areal temporal patterns were derived by calculating areal rainfalls for significant rainfall events in data dense regions for a number of areas, durations and orientations. In each temporal pattern region the 10 largest areal rainfall events were selected for use with ARR 2016 (Podger et al. 2016). Due to a lack of data availability, temporal patterns often had to be borrowed from neighbouring regions and the selected patterns were not especially rare. For larger catchments, the spatial smoothing of the patterns will account for any associated peakiness of the more frequent patterns, but for the smaller areas this could be an issue. There is also more potential for embedded bursts within these patterns.

Similar to the point patterns, where the target site is in the vicinity of the boundary of the temporal pattern regions ARR recommends careful consideration should be given to examining patterns in the bins of adjoining regions.

2.5.5. Areal Reduction Factors

A modified Bell's method was used to derive the daily areal reduction factors that are recommended for use with the 2016 IFDs (Podger et al. 2015a). This involved placing hypothetical circular catchments of various sizes across the country and determining the areal IFDs and comparing them to the catchment average IFD of that catchment. For the sub-daily ARFs an areal rainfall grid was calculated over the capital cities of Melbourne, Sydney and Brisbane, and the areal rainfalls derived from this grid were compared to their respective average IFDs (Podger et al. 2015b). Equations were then fit to the data.

Both daily and sub-daily ARFs are constrained by the available data, and hence their accuracy at individual locations can vary as they apply either regionally or nation-wide. There is unlikely to be a consistent bias with these values and inaccuracies are likely to cause scattered over and underestimations.

2.6. BoM IFDs

The design rainfall developed by BoM as part of ARR 2016 is available on the BoM website (BoM, 2017). These values were extracted for the durations and AEPs shown in Table 1. The IFD grids are at a resolution of 0.025° (approx. 2.5km) and cover the entire country.

Table 1: AEPs and Durations for which IFD values were obtained

AEP (1 in x)	Duration (minutes)
2, 5, 10, 20, 50, 100	5, 10, 30, 60, 120, 180, 360, 540, 720, 1080, 1440, 1800, 2880, 4320

These values were derived by fitting frequency distributions via l-moments to AMS from sets of rainfall stations with sufficient records, pooling the data and then gridding it via ANUSPLIN (Green et. al. 2012). Typically, this data set matches at-site data well but can have localised bias depending on the area of interest. This can be due to the regionalisation and gridding steps cause some over-smoothing in areas with very steep rainfall gradients, which has been observed in some locations causing alternate IFD values to be derived (WMAwater, 2018) for use.

3. DERIVATION OF AT-SITE FLOOD FREQUENCY ANALYSIS

3.1. Extraction of Annual Maximum Series

Annual maximum series (AMS) data is extracted from the instantaneous flow data derived from the water level gauge readings and the rating curve (refer to Sections 2.3 and 2.4). The flow data is segregated by year and passed through data filters to ensure that:

- The maximum flow for a given year is captured within the dataset,
- The maximum flow is a legitimate reading, and
- The same event is not registered twice over two different years, e.g. an event over December and January.

The filtering process for determining the true annual maximum flows was:

- Annual maximum events occurring in two different years were examined and assigned a single year of occurrence,
- The top 20% of AMS flows for a gauge were examined for missing peaks or erroneous level readings identified by volumes that did not match the daily rainfall depths of BoM daily read rainfall gauges situated near or in the catchment,
- Identified false readings had the event removed and the next biggest event was examined until a suitable event was identified for the year,
- Events with peaks missing were censored and defined as an event existing above a threshold corresponding to the last data reading available for that event for the Bayesian fitting method (refer to Section 3.3)
- Of the bottom 80% of AMS flows, events were flagged that had ≥14 consecutive missing days and ≥75% of the total record missing, and
- The flagged events were manually inspected and false flags such as gauges that do not operate for parts of the year were kept in the AMS data set while the rest were removed.

The resultant maximum flows from each year after filtering formed the annual maximum series. The length of record in years is compared to the number of final AMS in Figure 3. A list of the gauges used, their number of AMS and derived at-site flood frequency estimates are summarised in Table C1.

3.2. Assessing Quality of Rating Curves

There is an inherit uncertainty in deriving flow estimates based on the stage-discharge relationship, especially in the extrapolated zone where there is a higher level of uncertainty. An investigation was completed to determine the quality and overall reliability of each gauge. As an initial indication of the reliability of the rating curve, the Maximum Rated AEP was calculated and can be seen in Figure 4. The Maximum Rated AEP was determined using the flow at the maximum gauged level compared to the ARR Project 5 estimated design event quantiles. From this, it was found that most of the gauges had a Maximum Rated AEP more frequent than the 50% AEP, i.e. the largest flood recorded was less than the 50% AEP event. The rarest Maximum Rated AEP at any gauge was a 5% event.

Further investigation was completed to provide further insight in the quality. This was undertaken via a visual inspection of the rating curve and all recorded gaugings. The following aspects were examined:

- Distribution of gaugings to the rating curve (whether the distribution was scattered or provided a good fit),
- The fit of the extrapolated curve, and
- The maximum recorded gauging and the closeness of fit to the rating curve.

Following this, the Maximum Rated AEP was revised for eight (8) gauges where the revised Maximum Rated AEP was reduced to either the 20% AEP or 50% AEP (shown in Table C1) due to data problems. Confidence in rating curves was further refined by reviewing previous studies in the vicinity of these gauges. Confidence was improved where rating curves were determined to be valid and where rating curves were replaced with those with good fits from studies. Confidence was lowered in some cases where ratings were inconsistent.

The Maximum Rated AEP was used directly as part of the cost function used to calibrate the design event method to match at-site FFA (refer to Section 5.1).

3.3. Fitting Probability Distribution to AMS

Using FLIKE (Kuczera, 1999), Log-Pearson Type III (LP3) and Generalised Extreme Value (GEV) distributions were fit to the AMS sets using Bayesian and L-moment fitting techniques. H shifted L-moments were also trialled for values of H from 0 to 6 to determine the possible best fit. L-moments with higher H values place higher weightings to the rarer AMS points. While the GEV and LP3 distributions and different fitting techniques were investigated for the original 48 catchments, the full data set adopted the LP3.

These AMS sets were filtered using the multiple Grubbs-Beck test for low outliers (Cohn et al. 2013). This test identifies low flows that could affect the fit to the upper end of the distribution. Identified low flow outliers were set as points below threshold for the Bayesian fits. For events identified as missing peaks (refer to Section 3.1), their value was set as a number of events above a threshold in the FLIKE Bayesian solver. The probabilities of the AMS were taken from the Bayesian fits as they utilized the point below threshold method.

The R^2 of the FLIKE derived distributions in comparison to the AMS was derived and is shown in Figure 5. This highlights that the Bayesian fitting method gets consistently better fits than using L-moments. Although the GEV distribution has less very low R^2 values, the LP3 has a higher median and higher R^2 values on average therefore it was chosen as the distribution to represent all gauges. Of the Bayesian LP3 fits with low R^2 values, several were gauges with known data or rating curve errors, so it was deemed of less significance that these distributions could not be fit well. Figure 6 demonstrates a typical set of fits where there is a reasonably good match to the AMS. Figure 7 depicts an example of a difficult fit, where no probability distribution can match the shape of the AMS due to for the high flows being similar. A single distribution was chosen to ensure consistency and more directly comparable results.

For the gauges identified in this study, the RFFE estimates design event quantiles for the upstream catchment area was used for comparative purposes. Project 5 At-site FFA were also used as comparison to the derived At-site FFA. All of these estimates are shown for every gauge in Appendix A.

4. APPLICATION OF ARR 2016 METHODOLOGY

To compare At-site FFA to the design event method and determine if there is a consistent over or underestimation, standard ARR 2016 methodology needed to be applied to the 165 test catchments chosen for this study with default recommended design inputs. This section details the inputs and hydrologic configuration that was developed to create design event method estimates.

4.1. Catchment Delineation using the BoM Geofabric

While the BoM Geofabric provides surface runoff catchments and stream routing behaviour to other catchments, the catchments were too small relative to the size of the total upstream area for many of the gauges, resulting in a very large number of sub-catchments that were impractical to model. It was also noted that for the gauges with large upstream areas the BoM Geofabric catchments had inconsistently elongated shapes. Due to the nature of the Watershed Bounded Network Model (WBNM) stream routing, which assumes a constant stream length to area relationship, inconsistency in sub-catchment shape will result in false assumptions about stream routing times if a singular streamflow routing parameter is used.

BoM Geofabric sub-catchments were iteratively aggregated from downstream to upstream, joining catchments and updating their routing properties to attempt to achieve approximately 100 total sub-catchments without an individual sub-catchment exceeding 11% of the total upstream catchment area. These numbers were chosen as they are the upper limit of number of sub-catchment before peak flows are affected by the sub-catchment breakup. The number of sub-catchments before and after aggregation can be seen in Figure 8 for the original 48 test catchments. One example of a catchment before and catchment aggregation can be seen in Figure 9.

4.2. WBNM Model Configuration

WBNM was chosen as the hydrologic model to undertake the ARR 2016 design event method as it is generally insensitive to routing parameters, simplifying the necessary assumptions in this regard. The required WBNM inputs are:

- Upstream and downstream sub-areas
- Catchment area
- Catchment routing parameter (C)
- Impervious area
- Channel routing
- Temporal pattern
- Rainfall depths
- Initial loss
- Continuing loss

The connection of upstream and downstream sub-areas was determined from the catchment delineation created from the BoM Geofabric. The catchment areas were also determined from this file.

A catchment routing parameter (C) of 1.7 was used for every catchment based off recommendations in ARR 2016 Book 7 Chapter 6 (Boyd, 2016). Since most gauges are situated in rural catchments for every sub-area impervious areas were assumed to be 0. For catchments with small amounts of development and unmodified streams a stream lag factor of 1 is recommended (Boyd et. al. 2012), and hence was used in this study.

The remaining design inputs were all the recommended default values of ARR 2016. The ARR 2016 temporal patterns were applied for the relevant region, durations and AEPs. IFD rainfall depths were extracted by averaging the rainfall depth of grid cells within each sub-area and applying that rainfall to the entire sub-area. Burst initial loss values were derived by taking the ARR Data Hub storm initial loss of each sub-area and subtracting the associated median pre-burst. Each sub-area also had their own continuing loss values applied.

The WBNM model was then run for the 10 temporal patterns at each of the AEPs and durations shown in Table 2. For catchments with areas larger than 75km^2 the areal temporal patterns were used, although the minimum duration for this dataset is 720 minutes. There are a number of catchments with areas up to 250km^2 where the critical duration was found to be 720 minutes applying the areal temporal patterns. At these catchment sizes the areal smoothing of rainfalls is less pronounced (Podger et. al. 2016) and it was deemed of more importance to find the true critical duration, so the point temporal patterns were used in these instances.

Table 2: AEPs and durations assessed in the hydrological model

AEP (1 in X)	Duration (minutes)
2, 5, 10, 20, 50, 100	30, 60, 120, 180, 360, 540, 720, 1080, 1440, 1800, 2880, 4320, 5760

Critical durations for each AEP were determined by taking the mean peak flow of the 10 temporal pattern runs and finding the duration with the maximum mean peak flow. This resulted in the critical durations shown in Figure 10.

4.3. Routing Parameter Sensitivity

Although the recommended C for WBNM in NSW is 1.7, this can be further refined for individual catchments by matching modelled flows to observed flows for a number storm events. To test the sensitivity of the model to assuming this C, a value of 1.5 was also run for the original 48 test catchments. This yielded the peak flow changes that can be seen in Figure 11. In general, a smaller C will create a peakier hydrograph and hence lead to higher peak flow estimates. While this may be closer in comparison to the At-site FFA, there is no theoretical basis for it unless an event calibration has been carried out. Using an incorrect C will alter the relationship between event peak flow and volume, and hence it was decided to continue using the C of 1.7 unless there was sufficient evidence to do otherwise.

4.4. Results

Standard ARR 2016 method estimates for every gauge can be seen in Appendix B and Table C2. These highlight a strong trend of underestimation of the At-site FFA by the standard ARR 2016 method. This is further demonstrated in Figure 12 and Figure 13 which are a peak flow comparison of At-site FFA and the standard design event method and the percentage difference between these two sets of estimates at the 1 in 10 AEP respectively.

5. CORRECTION OF ARR BIAS USING OPTIMISED LOSSES

It may be possible to compensate for any potential bias in the ARR 2016 inputs and methods by simply modifying the initial and continuing loss values for a given catchment so that the design event method matches the At-site FFA. If losses need to be consistently increased or decreased this could indicate a general bias in the ARR 2016 method. Given the number of test catchments, manually adjusting losses would be inefficient and inconsistent. Therefore, the optimisation of a cost function via a solving algorithm was used to achieve the best match between the design event method and at-site estimates possible. This section of the report outlines the process used.

5.1. Cost Function

Using a solving algorithm requires the minimisation of a cost function. For this application the cost is the estimate from At-site FFA. As the design event method flow estimates tend to have increasing differences from the at-site FFA estimates at rarer AEPs due to the increase in uncertainty and the exponential increase in values, percentage differences of logged values at each AEP were used as per Equation 2.

$$Cost_{AEPx} = \frac{\ln Design\ event\ FFA_{AEPx} - \ln At{-}Site\ FFA_{AEPx}}{\ln At{-}site\ FFA_{AEPx}} \qquad (2)$$

The majority of the rating curves for the gauges in this study do not have gaugings for rare AEPs, and hence the certainty of high flow estimates is quite low. This extends to the At-site FFA fits at the rare end. It was therefore decided that the cost function should not place an equal weighting to all AEPs. The weightings applied to various AEP costs for different limits of rating curve confidence is shown in Table 3. The final cost function with weightings applied can be seen in Equation 3.

Table 3: Weightings applied at the various AEPs for different limits of rating curve confidence

AEP	Rating Curve Confidence Limit (1 in X AEP)			
	5	10	20	50
2	1	1	1	1
5	1	1	1	1
10	0.78	1	1	1
20	0.67	0.78	1	1
50	0.58	0.67	0.78	1
100	0.4	0.58	0.67	0.78

$$Cost_{Total} = \sum_{AEP=0.5}^{AEP=0.01} Cost_{AEP} \times Weighting_{AEP} \qquad (3)$$

Following the application of this cost function it became evident that the losses were fitting to the 1 in 2 AEP at the expense of the rarer AEPs. Considering the high level of variation in what combination of flood mechanisms can produce a 1 in 2 AEP flood event there is can be little consistency between it and the rarer AEP flood mechanisms. Hence to get reasonable fits to the more consistent sections of the design event method results, the cost weightings were changed to the values in Table 4. An example of an estimate at a gauge of before and after the weightings adjustment can be seen in Figure 14.

Additional cost of 1% was added to the total cost if either a value of continuing loss greater than 5mm/hr was applied or if the initial loss exceeded 50mm. If both the initial and continuing loss cut-offs were exceeded an additional 2% cost was used. This ensured that unrealistically high initial or continuing loss values were discourage unless they provided significant benefits to the fit.

Table 4: Final weightings applied at the various AEPs for different limits of rating curve confidence

AEP	Rating Curve Confidence Limit (1 in X AEP)			
	5	10	20	50
2	0	0	0	0
5	1	1	1	1
10	1	1	1	1
20	0.78	1	1	1
50	0.67	0.78	1	1
100	0.58	0.67	0.78	1

5.2. Solving Algorithm Configuration

The 'optimize.differential_evolution' function in the 'scipy' package in Python (Storn and Price 1997) was used as the solving algorithm for this study. The varied parameters were initial and continuing loss with the cost function described above to be minimised. The ranges in Table 5 were used as the boundary conditions for initial and continuing loss. The tolerance was set to 0.05 and for all other inputs default parameters were used.

Table 5: Minimum and maximum continuing and initial loss values allowed in the solving algorithm

Limit	Initial Loss (mm)	Continuing Loss (mm/hr)
Minimum	0	0
Maximum	100	8

An evolutionary solver was chosen as it is more likely to find an answer close to global minimum for interdependent parameters such as initial and continuing loss. The absolute minimum is likely not found with this algorithm however a solution that is very close to the absolute minimum cost should be achieved within this solution space.

5.3. Routing Parameter Sensitivity

To determine the sensitivity of the method to the assumed C, a value of 1.5 was also applied in the hydrologic model and the cost function applied to the at-site estimates vs the C of 1.5 design event method. This created the changes in peak flow estimates for the 1 in 10 AEP that can be seen in Figure 15 for the original 48 test catchments. It was found that changing C created higher costs in 3 test catchments and lower costs in only 2. Hence lower C values will not necessarily yield design event estimates that can more easily match at-site FFA.

5.4. Quality of FFA-Reconciled Fits

Figure 16 shows the final cost function estimates for the final FFA-Reconciled solutions. A number of gauges have relatively high costs including C2, E3, E5 and G1. These gauges had extremely poor rating curves, or AMS errors that led to poor FFA fits and were removed from the statistics in the rest of the report. Another issue is gauges that lie in urban catchments, these have high costs as the assumptions about routing and losses are incorrect, and hence D2 and D3 were removed from the statistics as they fit into this category.

Figure 17 shows a typical fit where the FFA-Reconciled estimate does not have a steep enough gradient. The design event method with 0 continuing and initial losses, upper bound losses and high initial loss and low continuing loss are also shown on the plot. This encompasses the solution space where 0 continuing and initial losses shows the highest estimates possible and upper bound losses show the lowest estimates possible. The high initial loss and low continuing loss design event method estimates represents the fit where the gradient is maximised, as more frequent rainfalls with lower depths are more affected by initial loss than rarer rainfalls with higher depths. This illustrates that despite the chosen loss parameters, a fit with an optimal gradient is not possible, and gradient must be low to get the desired accuracy at the ranges of the curve with the highest confidence in At-site FFA.

5.5. Results

FFA-Reconciled Losses Method estimates for every gauge are shown in Appendix B and Table C3 and Table C4. Table C3 contains all the gauges that were deemed to have good at-site FFA and quality fits whereas Table C4 contains all the gauges where it is likely fits are influenced by a poor at-site FFA or bias from other aspects of the method and inputs. The results demonstrate that by modifying standard ARR 2016 losses a much closer fit to At-site FFA can be achieved. This is further demonstrated in Figure 18 and Figure 19. These highlight that at most gauges a very close fit to the 1 in 10 AEP can be achieved by the FFA-Reconciled Losses Method. The FFA-Reconciled Losses Method estimates also demonstrate a tendency towards underestimation at the rare end of the probability distribution.

6. DISCUSSION

The At-site FFA has a relatively small source of inputs and bias. Although errors in rating curves are common they are more probable for rarer floods and are less likely to have a consistent bias. This means that the difference between the standard ARR 2016 method and the At-site FFA strongly indicates a systemic bias in the design event method inputs in NSW. The ability to achieve closer fits to the At-site FFA with the FFA-Reconciled Losses method demonstrates that much of this bias can be removed by using an alternate set of losses.

This section of the report discusses the potential sources of this apparent bias in the ARR 2016 method and some potential loss adjustments that could be applied in NSW to lessen the systemic bias.

6.1. Indications of Potential for Bias in ARR 2016 Design Inputs

6.1.1. Losses and Pre-burst Rainfalls

The initial and continuing loss values applied in the FFA-Reconciled Losses Method runs are shown in Figure 20 and Figure 21. Although the continuing loss values are typically lower than the ARR 2016 recommended values, it is difficult to identify a spatial trend, possibly due to the interdependence of these parameters. Therefore, the average infiltration rate was calculated for the critical events of the 165 test catchments using Equation 4 for both FFA-Reconciled Losses and Standard ARR 2016 methods. These values are displayed in
Figure 22 and Figure 23 respectively and compared in Figure 24. The percentage difference in average infiltration rate was then taken between the two methods and presented in Figure 25. This highlights that there is a strong trend in the reduction in overall losses for the FFA-Reconciled Losses set, which indicates that to get the Standard ARR 2016 method to match At-site FFA the losses would need to be reduced.

$$Average\ Infiltration\ Rate\ \left({mm}/{hr}\right) = \frac{Total\ Rainfall\ (mm) - Total\ Runoff\ (mm)}{Critical\ Duration\ (hr)} \quad (4)$$

The most robust method to determine the losses for a given catchment is to do event calibration on large flood events and use the mean of the set of losses needed to match these events. The method used in this study indicates that lowering losses will yield better design event method quantile estimates but it is difficult to isolate the extent to which the recommended losses contribute to the poor fit to At-site FFA. Given the underlying datasets the ARR 2016 losses are based on and the sensitivity of flood estimation to losses it is likely however that these values are playing a significant role in the systemic underestimation of design flood estimates on the NSW coast.

Lowering the storm initial loss as was done in the FFA-Reconciled Losses method, is effectively increasing the pre-burst. This change in losses could be due to errors in the pre-burst or the losses themselves. In general, the test catchments used in this study were less sensitive to initial losses (including pre-burst) than continuing losses, potentially as they were generally larger catchments. This can be seen in Figure 26, where the costs associated with fixing initial or continuing loss and using large values for the other loss is less for initial loss than it is for continuing loss. Applying this method to smaller catchments would provide additional insight into the validity of ARR initial losses, however catchment delineation could not be done with the BoM Geofabric and this is out of the scope of this study.

Sensitivity to pre-burst rainfalls and initial loss is more significant in small catchments. Recommendations for pre-burst including evidence that adopting the median pre-burst may under-represent the pre-burst distribution is discussed in Section 7.

Continuing loss is also lowered more consistently for the FFA-Reconciled Losses method, with 129 catchments having their continuing losses lowered and only 99 catchments having their initial losses lowered. Figure 27 demonstrates that in general initial losses are highly scattered with the FFA-Reconciled Losses method, and this is likely due to the interdependence of the losses and an artefact of the optimiser. It is however evident that continuing loss is playing a more significant role in the underestimation of design flood quantiles in NSW than the combination of initial loss and pre-burst.

A boxplot of the initial and continuing loss values for catchments deemed to have a reasonable calibration quality are shown in Figure 28. Figure 28 shows an increased spread of initial loss values for the FFA-Reconciled Losses method. This may indicate that the FFA-Reconciled Losses method initial losses have noise introduced from the calibration and are not fully reliable. For small catchment areas or for unrealistically high or low FFA-Reconciled Losses caution should be used when applying them to nearby catchments. It is also evident that the range of continuing losses from ARR is not reflected by the FFA-Reconciled Losses method and continuing loss values above 5mm/hr were not found for catchments with good calibrations and probably shouldn’t be used without local evidence.

6.1.2. IFDs and ARFs

The combination of IFD rainfall depths and ARFs creates areal IFDs. These values are the most important input into the hydrological model as they are the basis for assigned AEPs and are the driving mechanism of flooding. Errors in these estimates will therefore have a large impact on design event method estimates. When the areal IFDs are too high, they can be compensated for by the losses, and it can be hard to separate these two variables. One example of a catchment with areal IFDs that are likely too high can be seen in Figure 29. The surrounding catchments do not need losses of the same magnitude to match At-site FFA, and these catchments are within what is a likely rain shadow, where much of the rainfall for events falls on the face of the mountains to the east and reduced rainfall occurs over the range. As the IFD process used elevation as a covariate for gridding which does not allow for rain shadow effects it is possible it has overestimated the IFDs in this area.

When areal IFDs are too low, it may be impossible to match At-site FFA even with zero losses. There is some potential for the temporal patterns to play a role in underestimation although the design event method is much more sensitive to input IFDs. There were 30 instances where the calibration used less than 0.01mm/hr continuing loss to get the best fit to At-site FFA and still achieved a relatively high cost. Although there are numerous cases of these occurrences it could easily be attributed to At-site FFA errors. The BoM IFDs generally achieves relatively low residuals to site rainfall frequency estimates (WMAwater, 2018) which make the possibility of a state-wide bias unlikely.

6.1.3. Temporal Patterns

All the catchments investigated in this study lie in the temporal pattern regions of East Coast South and Southern Slopes Mainland. As the ARR 2016 temporal patterns are ensembles of 10 observed rainfall events from the relevant temporal pattern region that are scaled to match local IFDs, a tendency towards underestimation across all durations for multiple regions is highly unlikely. There is a possibility that individual ensembles of temporal patterns may by chance give lower peaks than typically observed values but the influence of this possibility could not be observed on the scale of the underestimation identified in this study.

When using point temporal patterns, small inconsistencies can be observed at the AEP where the temporal pattern bin changes. One example of this is shown for catchment E10 in Figure 30. This can be corrected by using an extra temporal pattern bins at the transitions (as per ARR Table 2.5.4 Babister et. al. 2016). This in general has minimal effect on the magnitude of the results, although it highlights some sensitivity to the temporal pattern set used. This correction has not been applied in this study for simplicity, although lower costs could have been achieved in some catchments if there were more consistency in the final design event method distribution.

The ARR temporal patterns available from the ARR Data Hub provide metadata on each storm in the ensemble including location and it is good practice to check the location of the ensemble compared to your location of interest.

6.2. Potential Bias Correction Applications

A number of potentially simple adjustments to ARR 2016 inputs that could be used to reduce the tendency towards underestimation on the NSW coast are explored in this section.

6.2.1. Using 75th percentile pre-burst

One way to effectively decrease the initial loss estimates and hence increase the peak flows of the ARR 2016 method is to use the 75th percentile pre-burst rainfall as opposed to the median pre-burst. The comparison of the resultant peak flows to At-site FFA can be seen in Figure 31 for the original 48 test catchments. This demonstrates that using a higher pre-burst does not have a significant effect on the results. This is somewhat expected given the insensitivity to initial losses in the FFA-Reconciled Losses method that is likely a result of the chosen catchment sizes. This option for correcting the NSW ARR 2016 bias has a relatively strong theoretical underpinning, but unfortunately it has minimal practical benefit for moderate to large-sized catchments.

6.2.2. Factored ARR losses

Another approach to minimise the bias of the Standard ARR 2016 method used was to apply a range of loss multiplication factors to the initial and continuing losses from the ARR Data Hub.

The average percentage difference of sites with a good fit (Table C3) in log space was taken at the 10% AEP as seen in Figure 32. This demonstrates less sensitivity to initial loss and a high sensitivity to continuing loss.

To test the viability of using alternate factored losses for different regions in NSW, the above process was repeated for catchments East and West of the great dividing range, resulting in the average percentage differences shown in Figure 33 and Figure 34. There are some differences using these regions, with catchments east of the range showing a greater sensitivity to initial loss. As there is less evidence to support changes in initial loss and the reduced sensitivity to it, it was decided not to apply a factored initial loss.

The optimal loss adjustment factors for continuing loss were 0.5, 0.38 and 0.42 for east of the range, west of the range and for all NSW catchments respectively. The optimal continuing loss factor chosen was 0.4 as it is the optimal solution statewide and the regional differences were not large enough to justify regionalisation. A comparison between at-site FFA and the Standard ARR 2016 method with the 0.4 continuing loss factor applied can be seen in Figure 35.

A slight additional bias of underestimation for larger catchment areas was found. To confirm possible bias four additional large catchments from the Hawkesbury/Nepean valley were added to the analysis. This included the Nepean, Nattai, Wollondilly and Cox River catchments. From this set there was one catchment that overestimated and three that were within the confidence limits using a 0.4 continuing loss. As a result, it was determined that there was not sufficient evidence to support using alternate adjustment factors with catchment area as the identified bias could be attributed to noise in the data.

7. MEDIAN PRE-BURST RAINFALL APPLICATION VALIDATION

The recommendation in ARR 2016 to use the median pre-burst rainfall assumes that its use will yield the runoff associated with the AEP of interest. This assumption may not be valid due to the highly skewed nature of most pre-burst rainfall distributions and the existence of zero pre-burst for large portions of the distribution.

To validate the use of the median pre-burst and the use of the median initial loss, for all pre-burst grid cells in NSW that have initial loss values, Monte Carlo sampling was utilised to create runoff estimates. These runoff estimates do not consider the use of temporal patterns or continuing losses but instead reflect the volume of a storm that has the potential to runoff. This method assumes that both the pre-burst rainfall distributions and the initial loss estimates are correct. The validation method was applied to the AEPs and durations listed in Table 6, as these are the AEPs and durations of pre-burst supplied via the ARR Data Hub.

Table 6: Durations and AEPs used for pre-burst rainfall validation

AEP (1 in x)	Duration (min)
2, 5, 10, 20, 50, 100	60, 90, 120, 180, 360, 720, 1080, 1440, 2160, 2880, 4320

7.1. Method

The first step in the process to validate the use of the median pre-burst was to randomly sample 5000 AEPs from the uniform distribution to be applied to all grid cells of interest in NSW. While a larger sample will increase the accuracy at rarer AEPs, the rarest AEP of interest is the 1 in 100, and 5000 samples will yield relatively stable estimates. Five thousand pre-burst rainfall and initial loss quantiles were also sampled from the uniform distribution to be applied at all locations in NSW.

At a given grid cell the sampled rainfall AEPs were converted to design rainfall depths using the BoM 2016 IFDs. The updated Illawarra and Coffs Harbour IFDs (WMAwater 2018) were not used for simplicity and because it is unlikely alternate design rainfalls will have a large impact on the focus of this investigation which is pre-burst rainfalls and initial losses. For sub-daily rainfalls rarer than 1 in 100 AEP the pre-burst rainfall distribution was used to obtain pre-burst rainfall depths for all the sampled quantiles at location of interest. The ARR 2016 standardised initial loss distribution was used in conjunction with the median initial loss at the location of interest to convert initial loss quantiles to an initial loss value.

For each sampled set of pre-burst rainfall and initial loss, the pre-burst rainfall was subtracted from the storm initial loss and values less than zero were set to zero. This derived value is known as the burst initial loss (IL_B). IL_B was also calculated just using the median and not the sampled initial loss so the effect of initial loss sampling could be determined. IL_B was then subtracted from the sampled rainfall and if this value was less than zero it was set to zero. This derived value will be referred to as the rainfall after initial loss is satisfied.

The rainfall after initial loss is satisfied results were then ordered and were assigned AEPs using the Cunnane plotting position formula shown in Equation 5, where r represents the rank of the event in the set and n represents the sample size (in this instance 5000). This process was undertaken to get probabilities for rainfall after initial loss is satisfied using the Standard ARR 2016 method (median initial loss and median pre-burst), sampling only pre-burst and for sampling both pre-burst and initial loss.

$$AEP = \frac{r - 0.4}{n + 0.2} \tag{5}$$

7.2. Results

The three sets of sampled rainfalls after initial loss is satisfied are displayed in Figure 36 for a grid cell near Wollongong. Rainfall is also included on this plot for comparison and the rainfall after initial loss is satisfied ordered by rainfall AEP is also included to demonstrate the range of differences between rainfall and rainfall after initial loss is satisfied for the various methods. This demonstrates that in this location there is a significant difference between the rainfall after initial loss is satisfied derived for the standard ARR 2016 method and from using the full set of distributions in a joint probability approach. It is also demonstrated that in this location sampling from the initial loss distribution does not have a substantial impact on results.

When looking at the entire state however, these results can vary, with the use of median initial loss instead of sampling having a larger impact in some area for some durations and AEPs. This is demonstrated in Figure 37 which shows the difference between rainfall after initial loss is satisfied when using median initial loss and initial loss sampling for the 1 in 2 and 1 in 100 AEP and the 3 and 12 hour durations.

Sampling initial loss and pre-burst rainfalls nearly always achieves higher rainfall after initial loss is satisfied and runoff estimates, as is demonstrated in Figure 38. Using the median pre-burst some areas of NSW will result in zero runoff for some durations and AEPs while there is substantial runoff when sampling pre-burst and initial loss.

7.3. Discussion

There are significant differences between using the Standard ARR 2016 method of using the median initial loss and pre-burst rainfall and using a joint probability approach which samples from rainfall, initial loss and pre-burst distributions. It is likely that using the Standard ARR 2016 method will overestimate losses and underestimate runoff.

As this investigation calculated the AEP neutral runoff, the simplest solution to address this issue is to determine the burst initial loss (IL_B) that could be applied at each AEP for each duration that would result in the runoff that would occur from sampling both initial loss and pre-burst rainfall.

This can be determined simply by subtracting the sampled runoff distribution from the sampled rainfall distribution for all the durations and AEPs listed in Table 6. This results in the burst initial loss (IL_B) grids shown in Figure 39. These values will be a more accurate statistical representation of burst initial loss than the Standard ARR 2016 method assuming both ARR 2016 initial loss and pre-burst are reasonably accurate.

Supplying only burst initial loss (IL_B) values presents issues for practitioners that have done a robust event calibration and have determined local storm initial losses that occur at the catchment of interest. While these storm initial losses could be transformed to burst initial losses (IL_B) using the Monte Carlo methodology presented herein, this is a technically complex approach. An alternative simplified ratio approach was investigated which can reliably convert storm initial loss (IL_{storm}) to burst initial loss (IL_B) and is presented in Equation 6.

$$IL_{B-chosen} = IL_{storm-chosen} \times \frac{IL_{B-ARR}}{IL_{storm-ARR}} \tag{6}$$

Where $IL_{B\text{-}ARR}$ is the burst initial losses derived in this section and supplied via the ARR Data Hub, $IL_{storm\text{-}ARR}$ is the ARR recommended storm initial losses, $IL_{storm\text{-}chosen}$ are the storm initial losses chosen based on local evidence and $IL_{B\text{-}chosen}$ is the burst initial loss that should be applied in hydrologic modelling associated with the Standard ARR 2016 design method. The difference quantiles between the burst initial losses derived via this method and using the full sampling approach for a 30% reduction in storm initial loss for every pre-burst grid cell for the 720min duration is shown in Table 7. This demonstrates that this simplified approach is an effective strategy for all AEPs other than the 1 in 2, with all grid cells being within roughly plus or minus 3mm compared to using the full sampling approach.

Table 7: Burst Initial Loss Difference Quantiles for the Simple and Sampled Methods for the 720min Duration (mm)

Quantile	AEP (1 in x)					
	2	5	10	20	50	100
0	-4.59	-2.26	-2.42	-2.19	-2.02	-5.92
0.025	-2.12	-1.08	-0.80	-0.94	-0.69	-3.97
0.05	-1.72	-0.85	-0.50	-0.73	-0.40	-3.36
0.1	-1.34	-0.64	-0.20	-0.54	-0.16	-2.66
0.25	-0.87	-0.36	0.17	-0.25	0.17	-1.73
0.5	-0.46	-0.07	0.46	0.19	0.52	-0.98
0.75	2.29	0.87	1.03	1.12	0.87	-0.37
0.9	10.20	1.46	1.66	1.74	1.33	0.52
0.95	11.82	1.69	1.85	1.97	1.67	0.85
0.975	12.90	1.82	1.97	2.15	1.92	1.01
1	15.00	2.42	3.02	3.16	3.33	1.89

8. CONCLUSIONS

Comparing At-site FFA to the Standard ARR design event 2016 method results highlighted that there is consistent underestimation associated with the Standard ARR 2016 method. An attempt to reconcile these differences was made by adjusting the initial and continuing losses in the Standard ARR 2016 method to match the At-site FFA method. This resulted in close agreement between the At-site FFA and the FFA-Reconciled Losses method.

The FFA-Reconciled Losses method had consistently lower FFA-Reconciled continuing losses and a range on higher and lower FFA-Reconciled initial loss estimates. This highlighted less sensitivity to initial losses which is likely due to the range of catchment areas investigated.

It was found that the best technique to reconcile differences between the Standard ARR 2016 method and At-site FFA on a state-wide basis is to apply a continuing loss factor of 0.4 to the Standard ARR 2016 method. However, as outlined in recommendations better local data should be used in preference.

This study has highlighted that for NSW using the default loss values from ARR Data Hub results in the significant underestimation of design flows and levels. This could result in the underestimation of risk to the public and undersizing of waterway infrastructure which could further increase the associated flood risks to the community.

While this study and the associated information was specifically developed to provide advice for OEH funded studies the implications are significant and broad reaching. Therefore, the information should be made available for the use of all practitioners in NSW via the ARR Data Hub.

This is the first large scale bias checking and validation of the ARR 2016 standard design event method and inputs. It is likely that similar or larger problems occurred with design methods in ARR 1987.

9. RECOMMENDATIONS

To address the issues identified in this report it is recommended that:

- A hierarchical approach to loss section and pre-burst be used (see Section 9.1)
- Changes be made to the ARR data hub to make this improved NSW data available to all practitioners (see Section 9.2)
- Further analysis be undertaken (see Section 9.3)

9.1. Recommendations for a Hierarchical approach to loss selection and pre-burst

A comparison of the investigated adjustment methods can be seen in Figure 40. This highlights that both adjustment methods outperform the standard ARR 2016 method approach and the 0.4 continuing loss factor will remove a significant amount of bias.

This work has shown that there is a considerable underestimation bias in the standard ARR 2016 method in NSW. Practitioners should use the following hierarchical approach (1 most preferred to 5 least preferred) to loss selection until better advice is available:

1. Use the average of calibration losses from the actual study if available
2. Use the average calibration losses from other studies in the catchment if available and appropriate for the study.
3. Use the average calibration losses from other studies in the similar adjacent catchments if available and appropriate for the study.
4. Use the FFA-Reconciled losses from Figure 20, Figure 21 and Table C3 (and available through the ARR Data Hub) for nearby similar sites. Caution should be applied when using FFA-Reconciled initial loss as it may not be well calibrated with the catchment size chosen in this study. Additional scrutiny should be applied to initial loss values for catchments of $100km^2$ or less.
5. Until revised losses are generated using better predictor equations (discussed in Section 9.3) use raw ARR Data Hub continuing losses with a multiplication factor of 0.4. Use the unmodified ARR Data Hub initial losses and apply additional scrutiny to them for catchment areas of $100km^2$ or less to ensure they are representative for the catchment.

This work has also demonstrated that the use of median pre-burst is highly unrepresentative of using the real pre-burst distribution for a number of durations. An alternative set of burst initial losses was presented that should be used instead of the median pre-burst and initial loss. These values are available on the ARR Data Hub as “Burst Initial loss” when a location in NSW is selected. A section on NSW Specific data is also available under the “Jurisdiction Specific” tab on the ARR Data Hub.

Table 8: Hierarchy of approaches from most (1) to least (5) preferred

Approach	Storm initial loss	Pre-burst	IL_B (IL_{Burst})	Continuing loss
1	Average calibration	Not required or back calculated using IL_{storm} - IL_B	Calculated using Equation 6	Average calibration
2	Average calibration	Not required or back calculated using IL_{storm} - IL_B	Calculated using Equation 6	Average calibration
3	Average calibration	Not required or back calculated using IL_{storm} - IL_B	Calculated using Equation 6	Average calibration
4	NSW FFA reconciled initial loss (see ARR Data Hub)	Not required or back calculated using IL_{storm} - IL_B	Probability Neutral Burst Loss available through ARR Data Hub	NSW FFA reconciled continuing losses where available (see ARR Data Hub)
5	ARR Data Hub initial loss	Not required or back calculated using IL_{storm} - IL_B	Probability Neutral Burst Loss available through ARR Data Hub	ARR Data Hub continuing losses multiplied x 0.4

9.2. Changes to the ARR Data Hub for NSW

An additional section has been added to the ARR Data Hub that can be found at http://data.arr-software.org/nsw_specific. This has a brief overview of the outcomes of this report and links to a losses map where catchments can be clicked on and the plots in Appendix B will be given. There are also links to this report and Appendix C tables.

Burst initial loss estimates detailed in this report are also provided via the main page of the ARR Data Hub. When selecting a catchment or point within NSW and ACT and retrieving data the extra burst initial loss dataset will be provided by default.

9.3. Recommendations for Further Analysis

This investigation also recommends that industry consider additional work in this area with the aim of further refining the least preferred approaches (4 and 5) in hierarchical approach to loss selection in NSW as well as improving the results available for RFFE in NSW.

It is likely that better loss estimates can be attained by deriving a relationship between other gridded parameters and the FFA-Reconciled continuing losses as was done for the ARR2016 losses. This would be based on a dataset of 180 catchments compared to the handful used in ARR 2016. A validation could be carried out using a leave one out analysis.

This will provide an unbiased defensible approach to flood estimation. As part of this work a similar study should be carried out on the smaller RFFE catchments to isolate bias in initial loss and resolve it.

This validation process could be improved with the derivation of more reliable rating for higher flow estimates and data quality of water level gauges needs to be maintained and improved. Better at-site FFA that could be achieved from higher data quality would greatly increase the quality of this analysis and allow for closer checking of the ARR method in the future.

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Figures

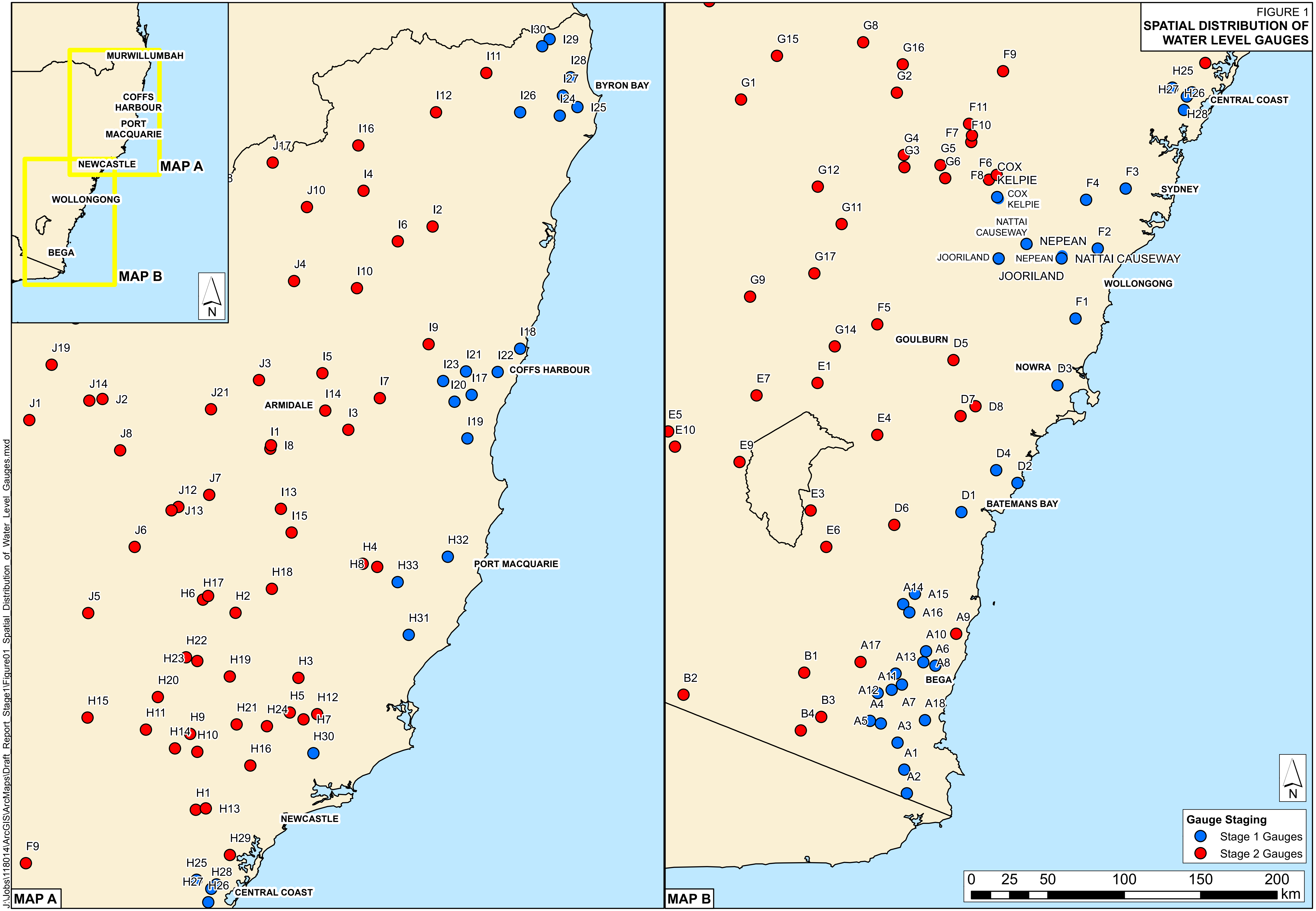
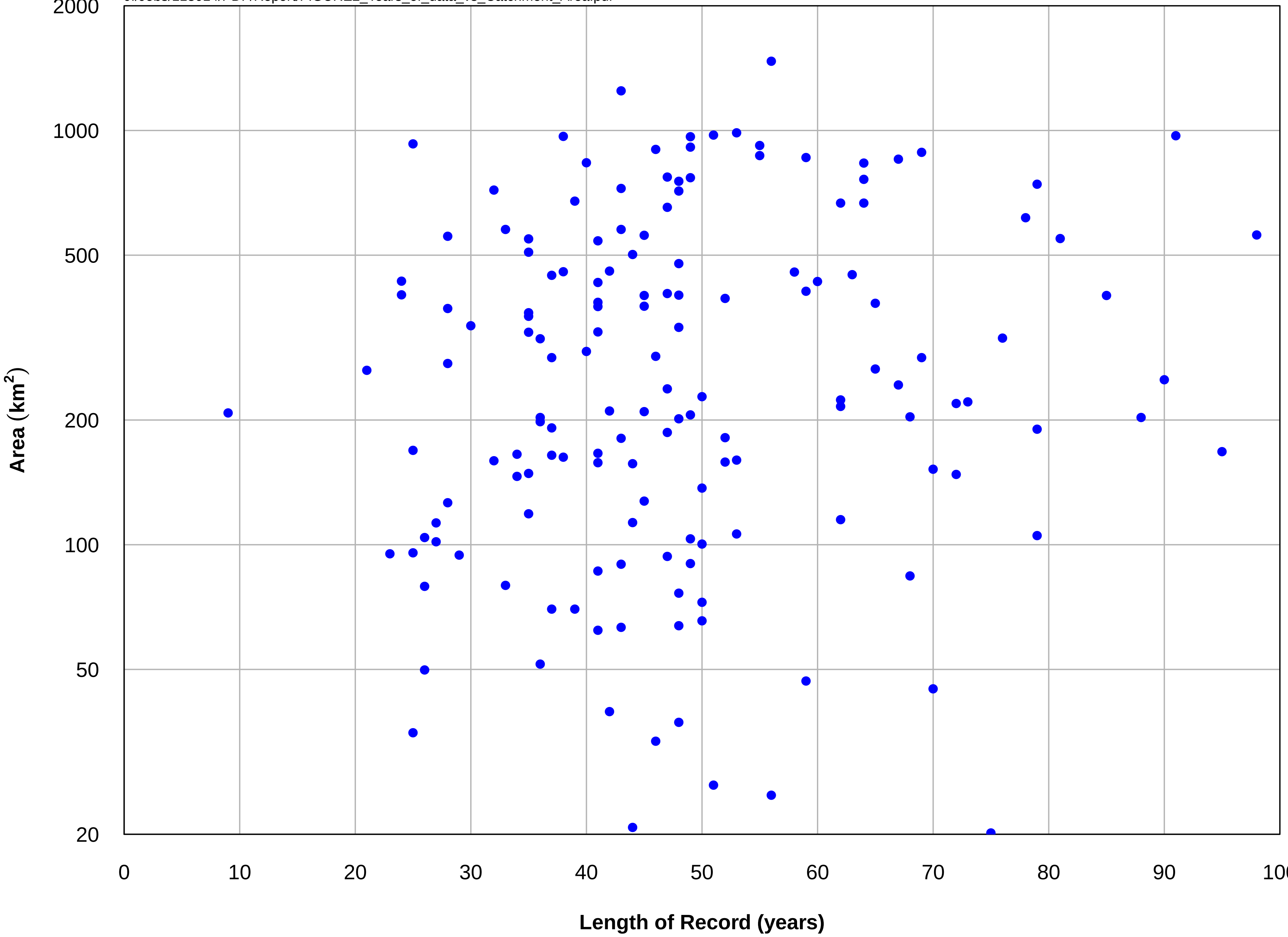


FIGURE 1
SPATIAL DISTRIBUTION OF WATER LEVEL GAUGES

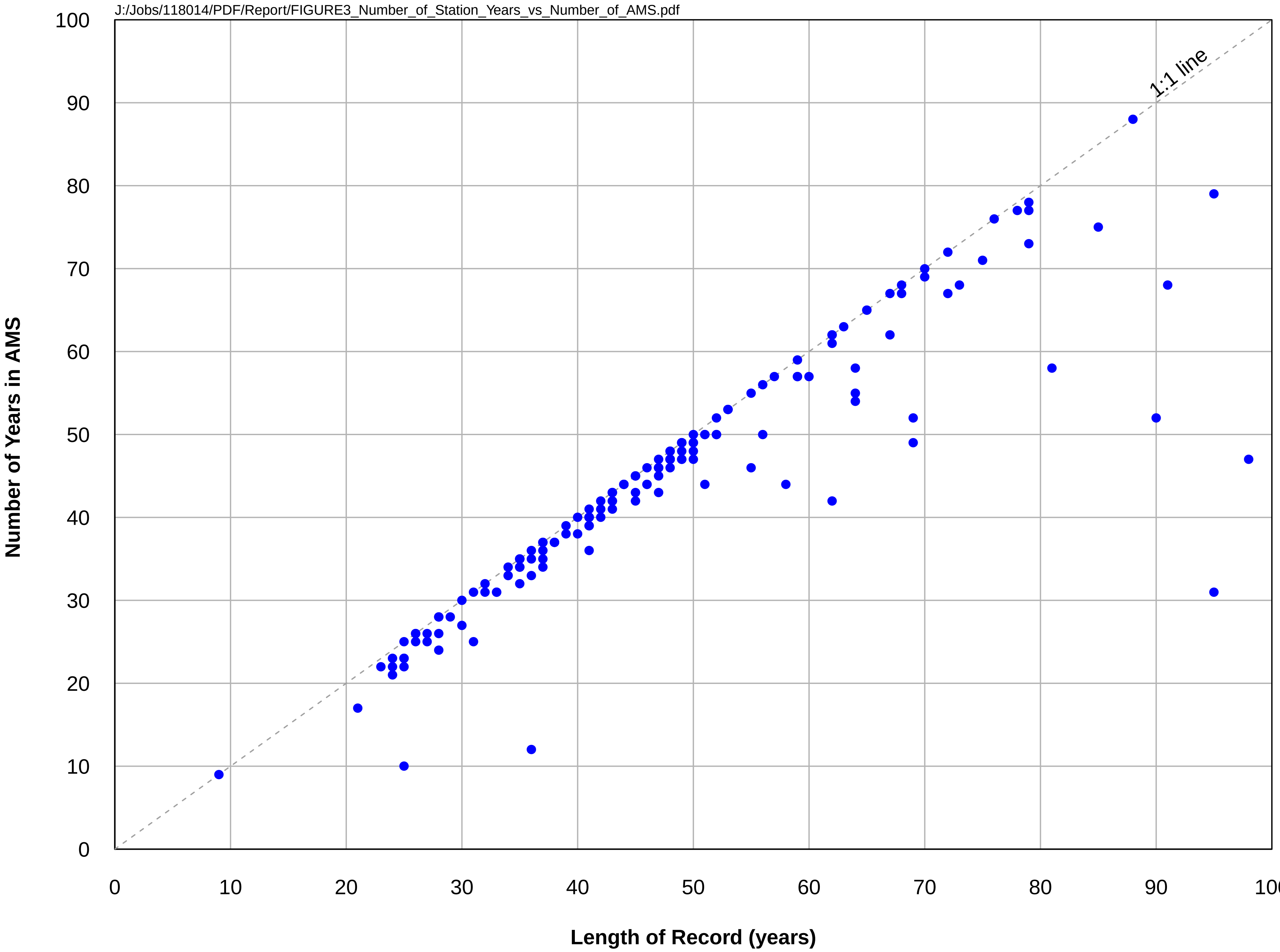
J:\Jobs\118014\ArcGIS\ArcMaps\Draft Report Stage1\Figure01 Spatial Distribution of Water Level Gauges.mxd

J:/Jobs/118014/PDF/Report/FIGURE2_Years_of_data_vs_Catchment_Area.pdf



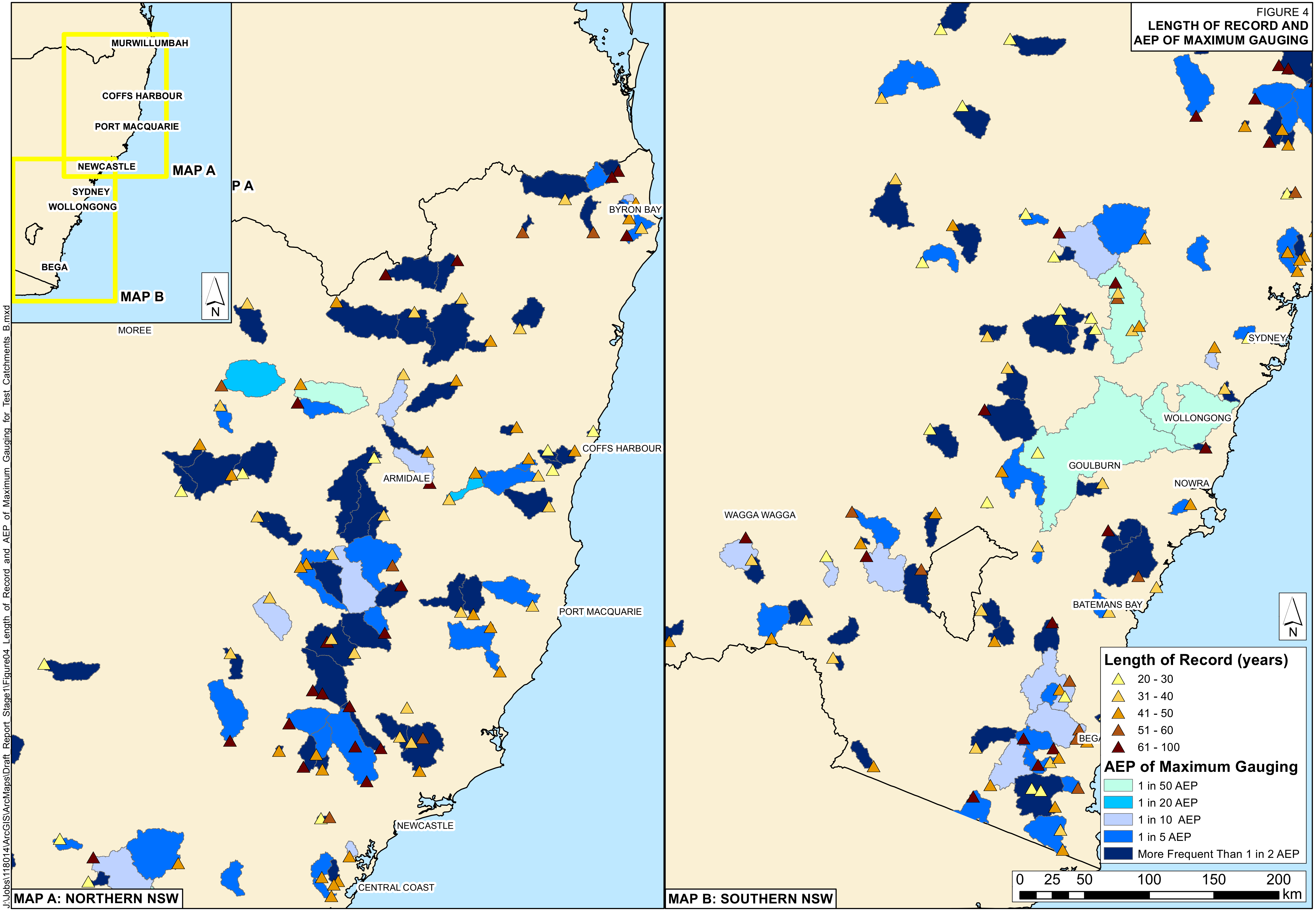
LENGTH OF RECORD VS CATCHMENT AREA

FIGURE 2



LENGTH OF RECORD VS NUMBER OF YEARS IN AMS

FIGURE 3



J:\Jobs\118014\ArcGIS\ArcMaps\Draft Report Stage1\Figure04 Length of Record and AEP of Maximum Gauging for Test Catchments B.mxd

J:\Jobs\118014\PDF\Report\FIGURE05_Probability_Distributions.pdf
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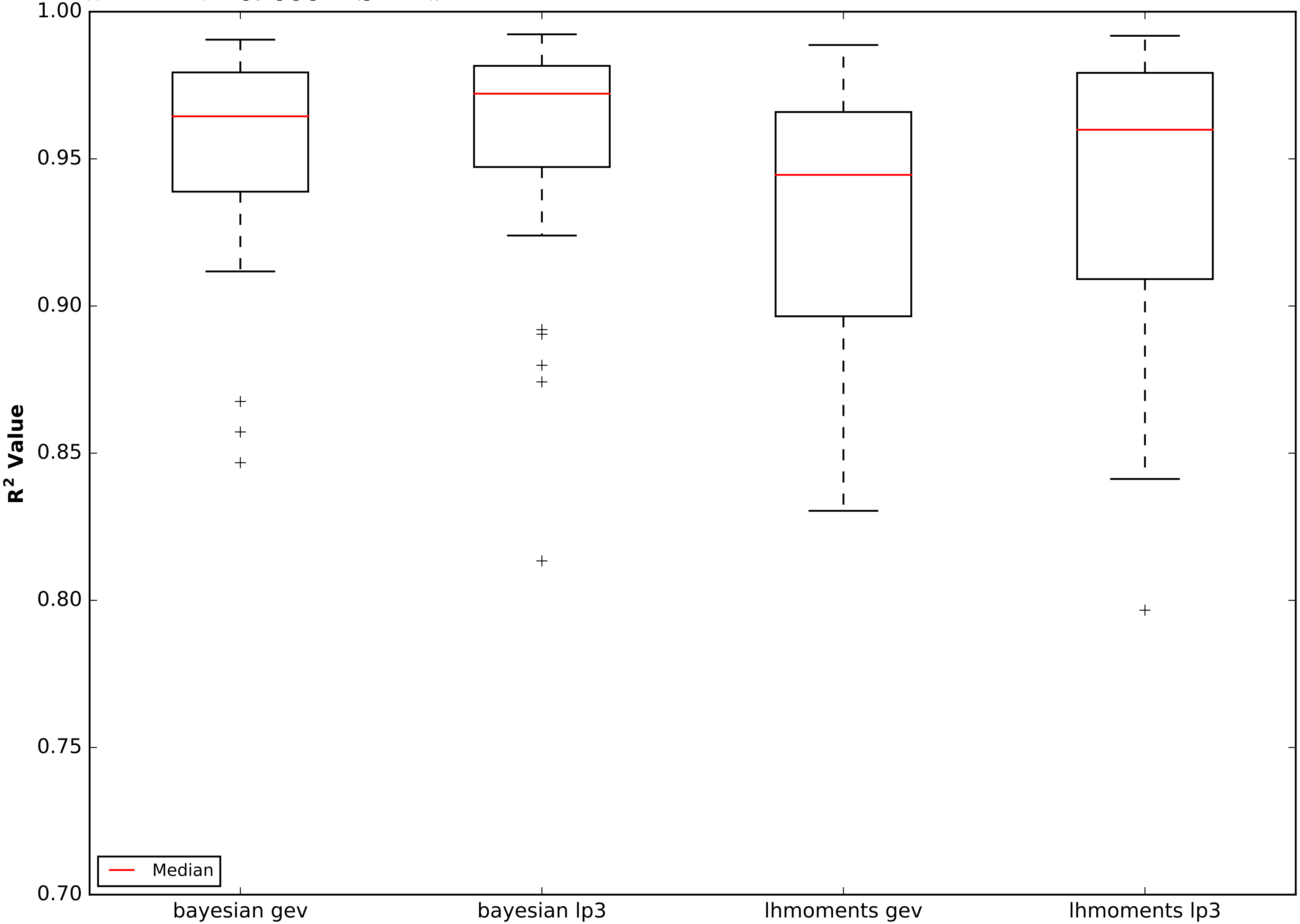
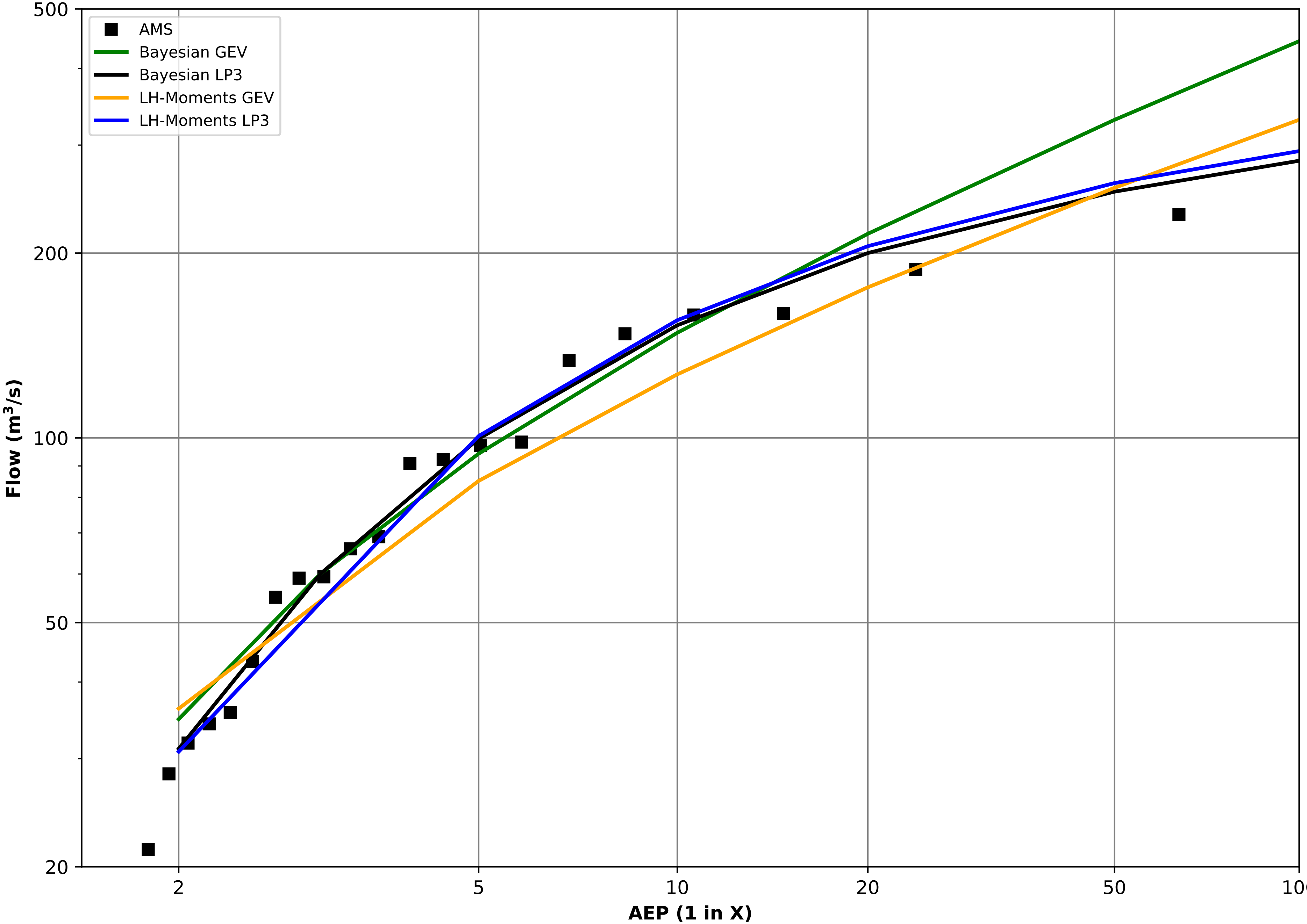


PROBABILITY DISTRIBUTIONS FIT TYPES

FIGURE 5

J:\Jobs\118014\PDF\Report\FIGURE06_Typical Probability Distribution Fit.pdf
J:\Jobs\118014\Software\plots\Pdf_Figure_08_10_18_33_Probability_Distribution.py



TYPICAL PROBABILITY DISTRIBUTION FIT
IMLAY RD BR (A1)

FIGURE 6

J:\Jobs\118014\PDF\Report\FIGURE07_Difficult Probability Distribution Fit.pdf
J:\Jobs\118014\Software\plots\Pdf_Figure_08_10_18_33_Probability_Distribution.py

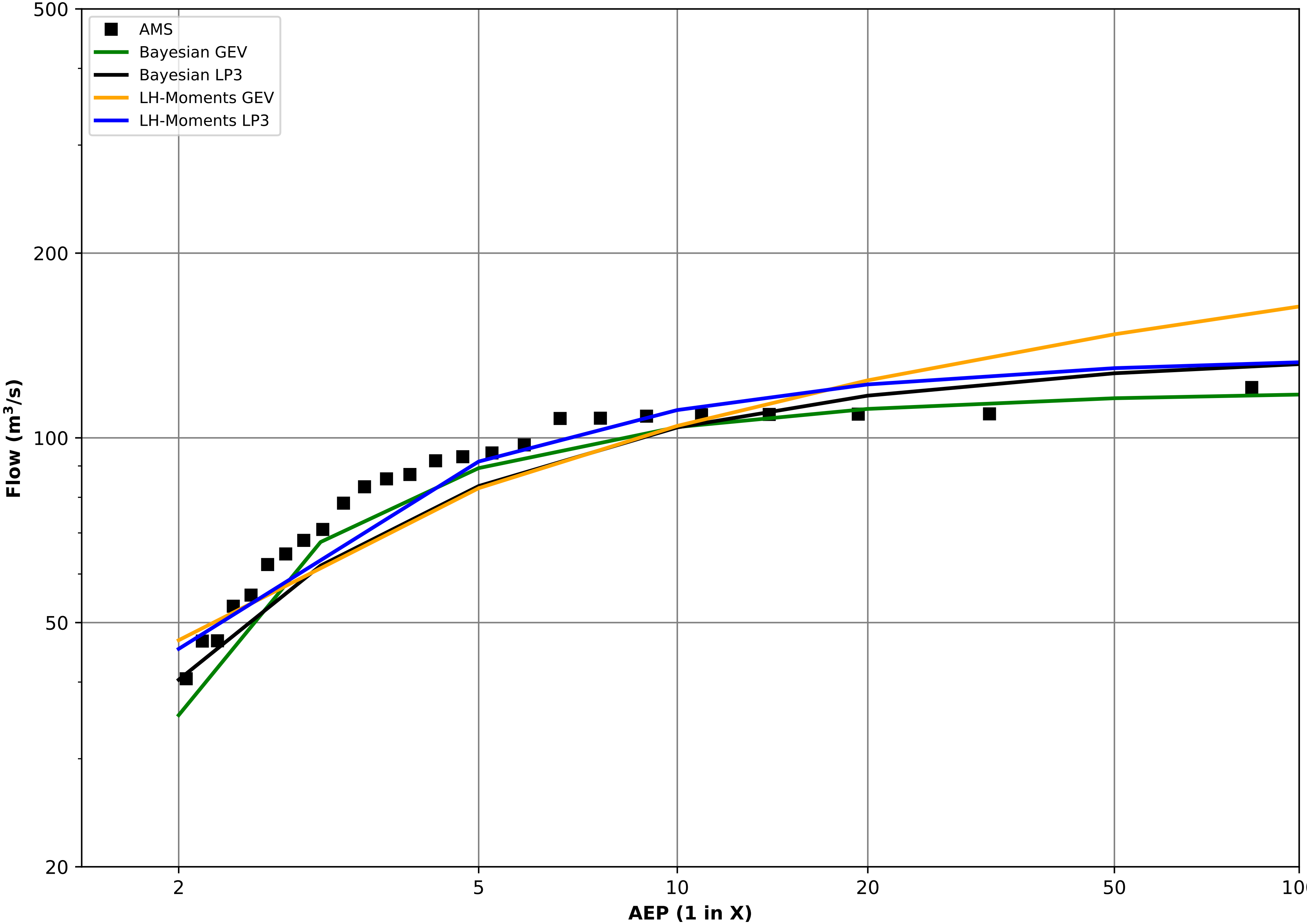


FIGURE 7

DIFFICULT PROBABILITY DISTRIBUTION FIT
AVONDALE (H29)

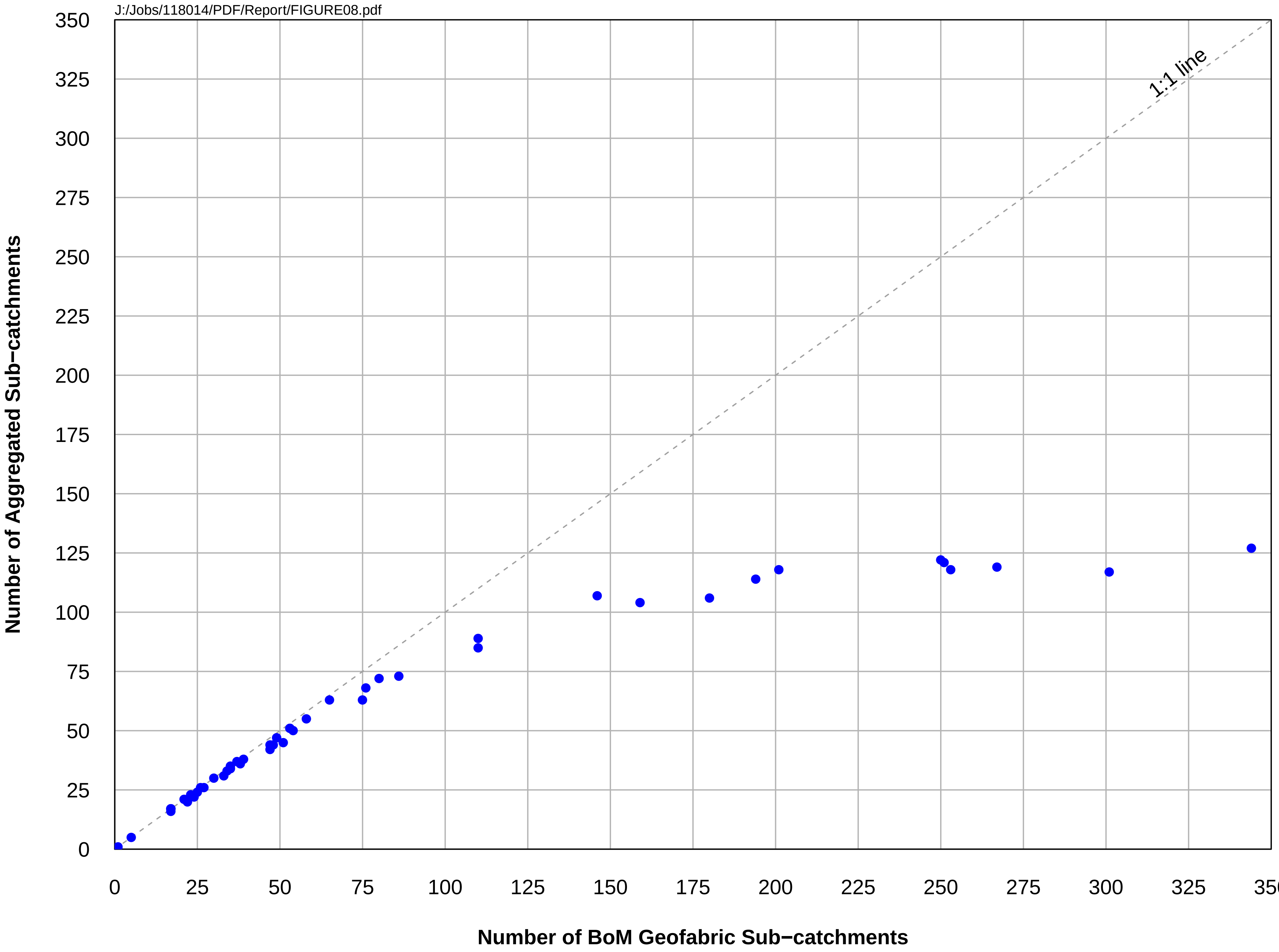


FIGURE 8
NUMBER OF GEOFABRIC SUB−CATCHMENTS VS NUMBER OF AGGREGATED SUB−CATCHMENTS

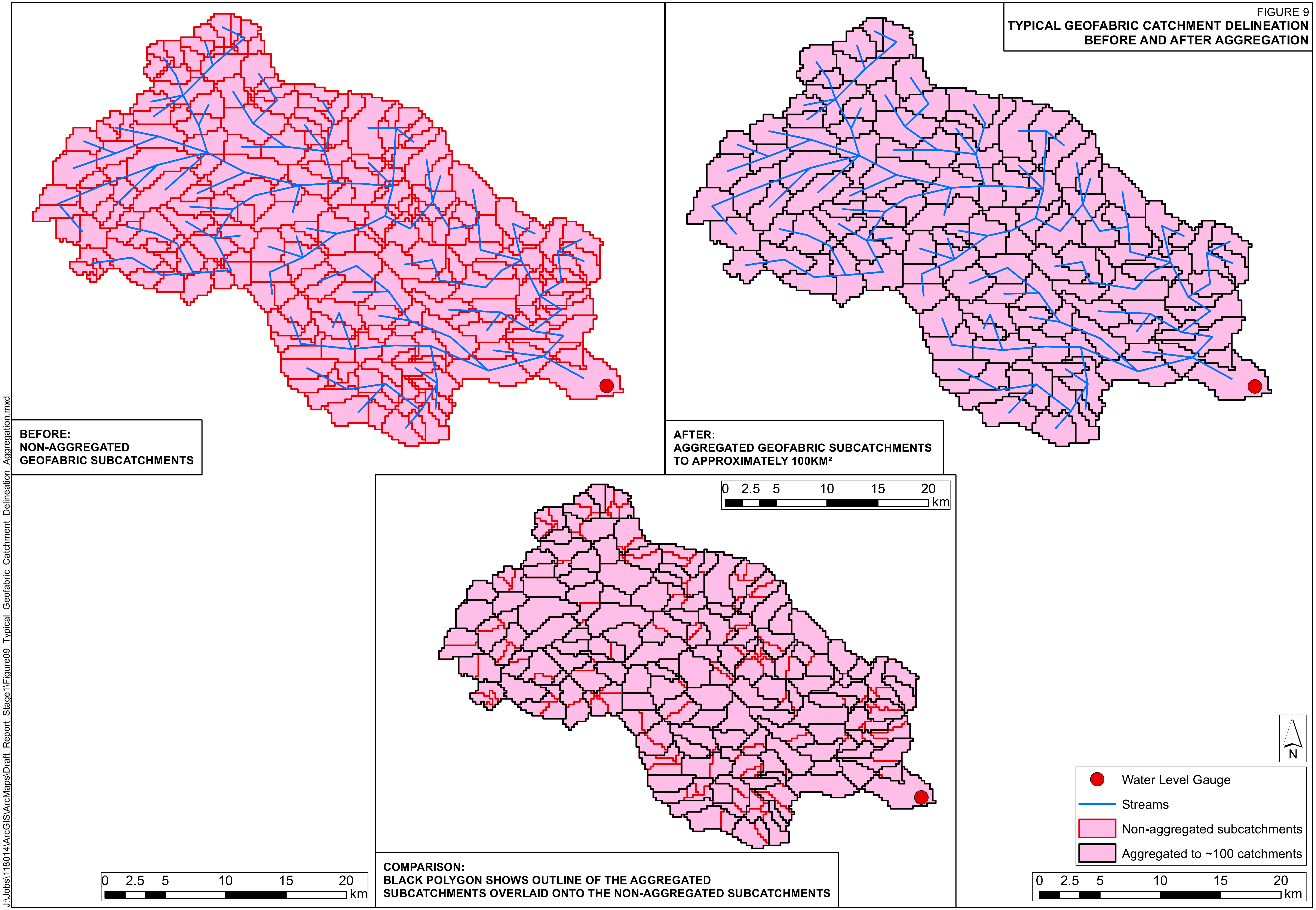


FIGURE 9
TYPICAL GEOFABRIC CATCHMENT DELINEATION BEFORE AND AFTER AGGREGATION

J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure09_Typical_Geofabric_Catchment_Delineation_Aggregation.mxd

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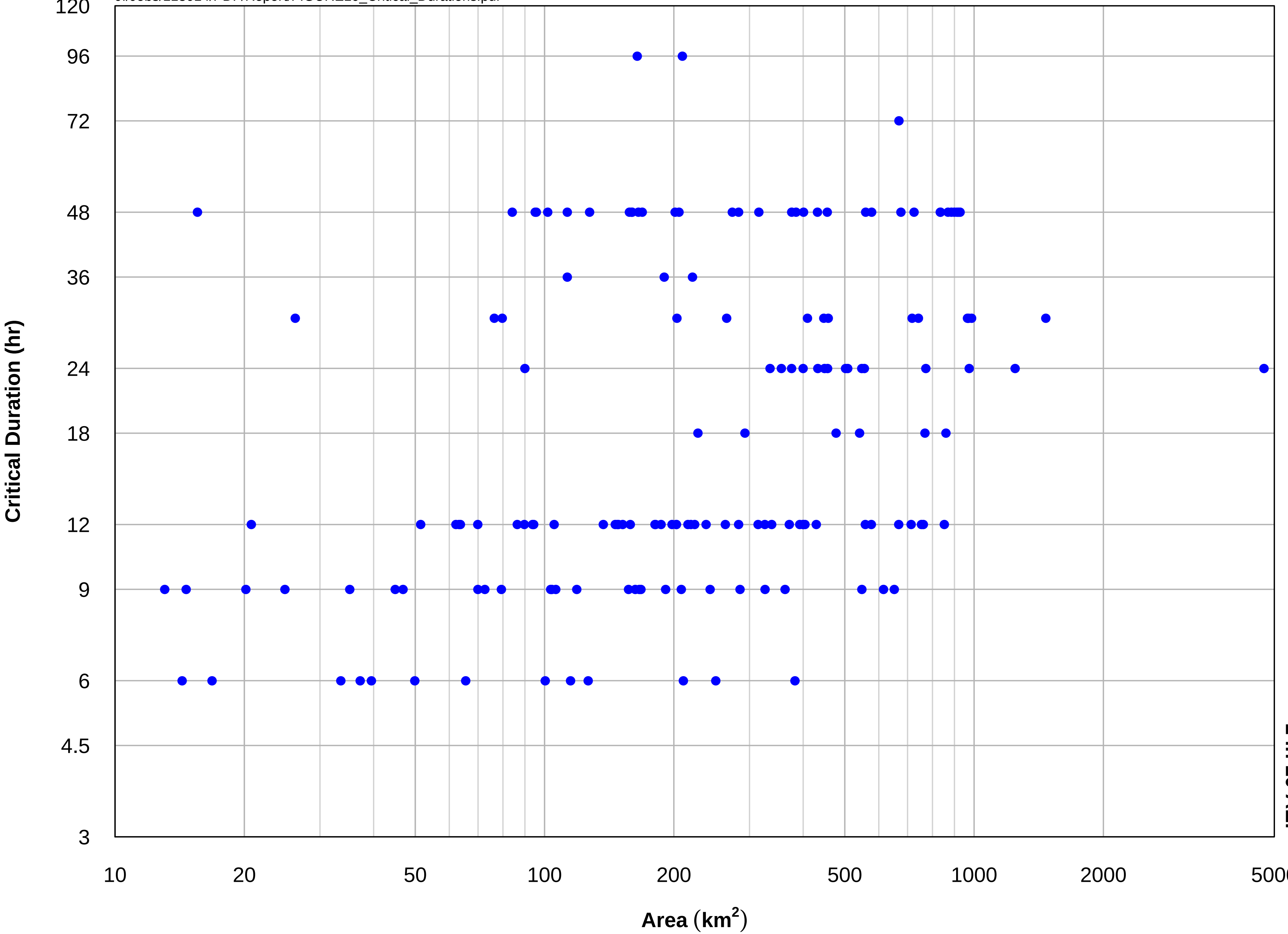


FIGURE 10
STANDARD ARR CRITICAL DURATIONS VS CATCHMENT AREA
1 in 10 AEP

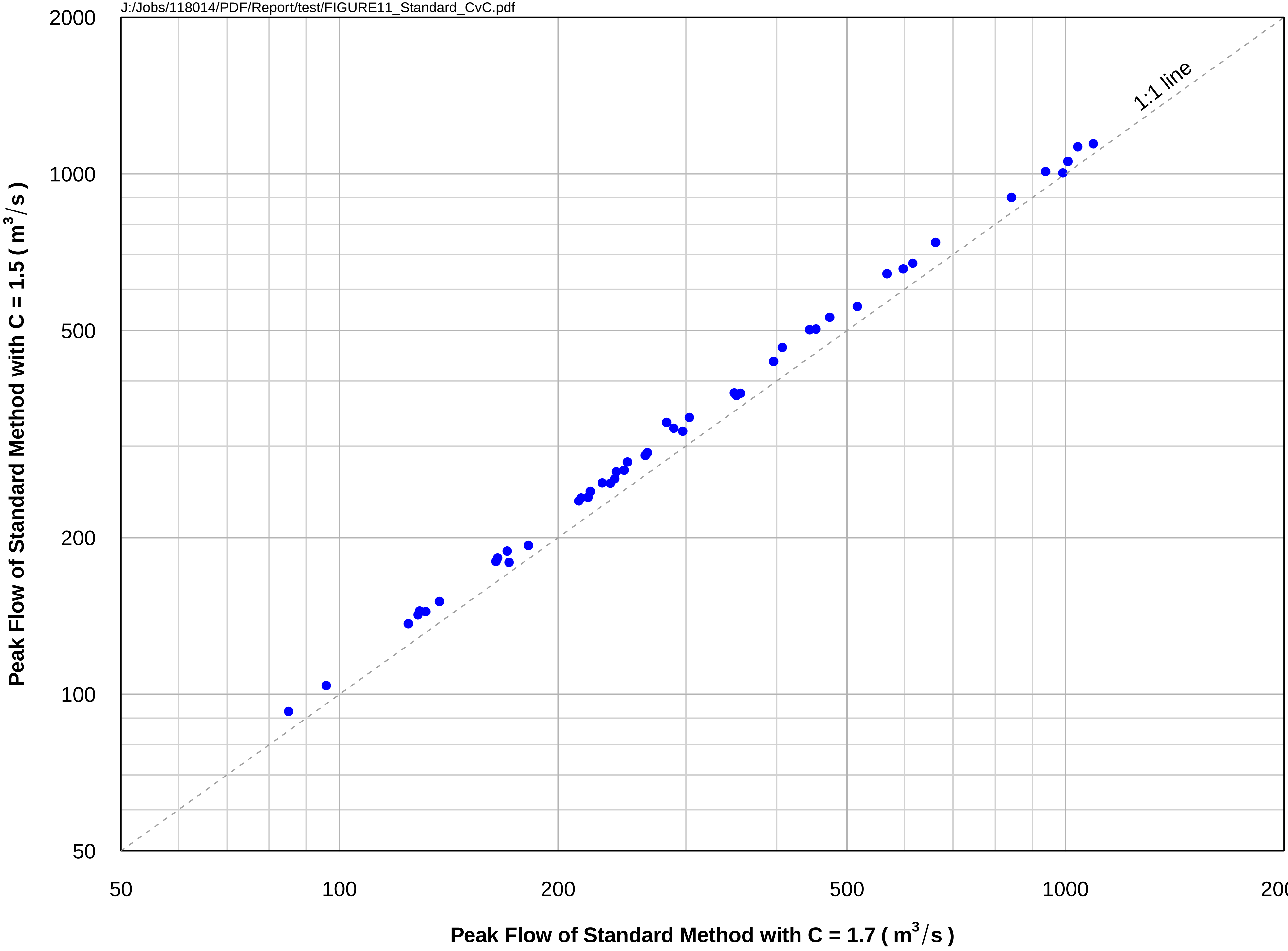


FIGURE 11

FLOW COMPARISON STANDARD ARR2016 METHOD 1 IN 10 AEP
CHANGE IN CATCHMENT ROUTING (C=1.7 VS C=1.5)

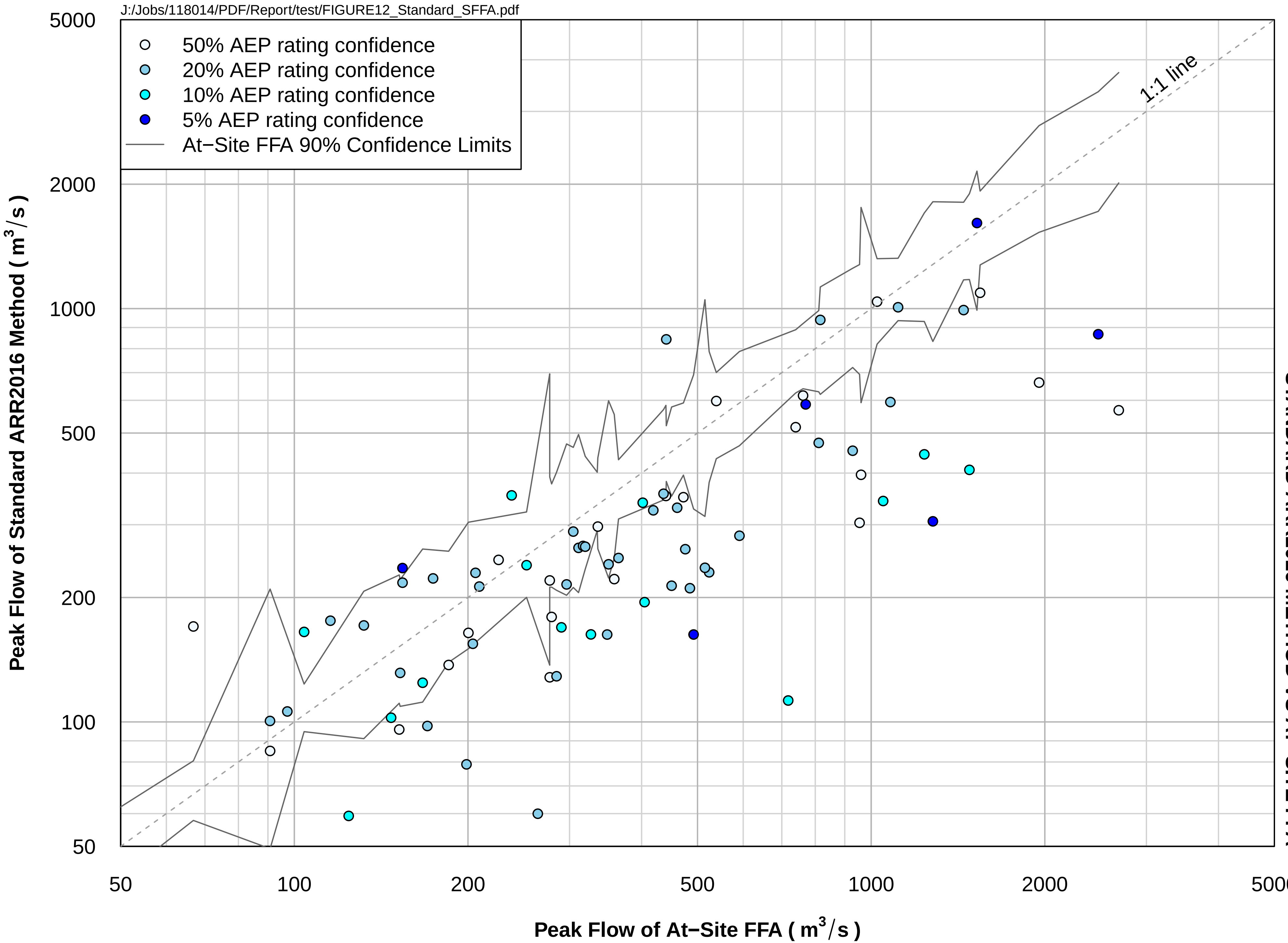
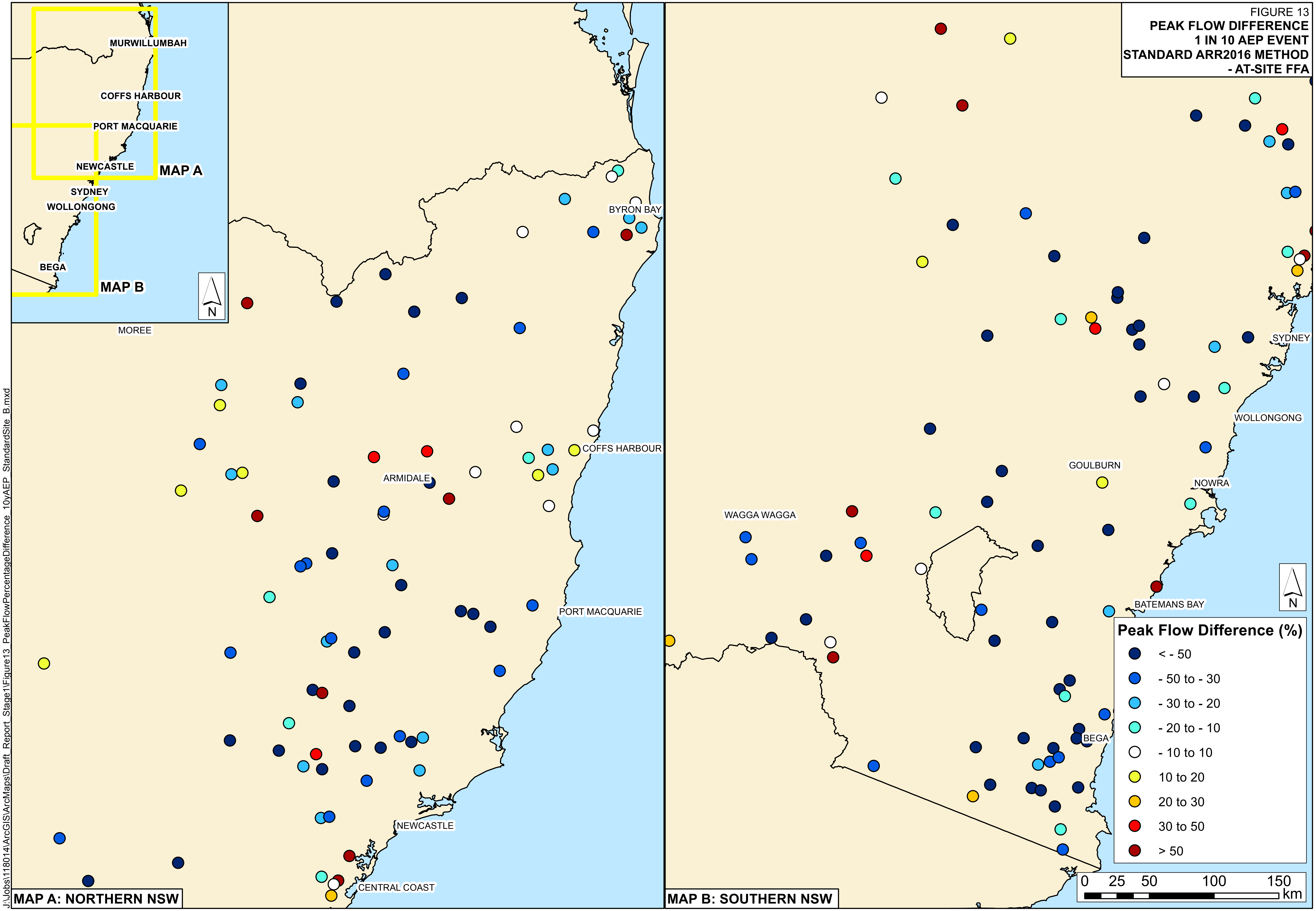


FIGURE 12
FLOW COMPARISON 1 IN 10 AEP
STANDARD ARR2016 METHOD VS AT−SITE FFA



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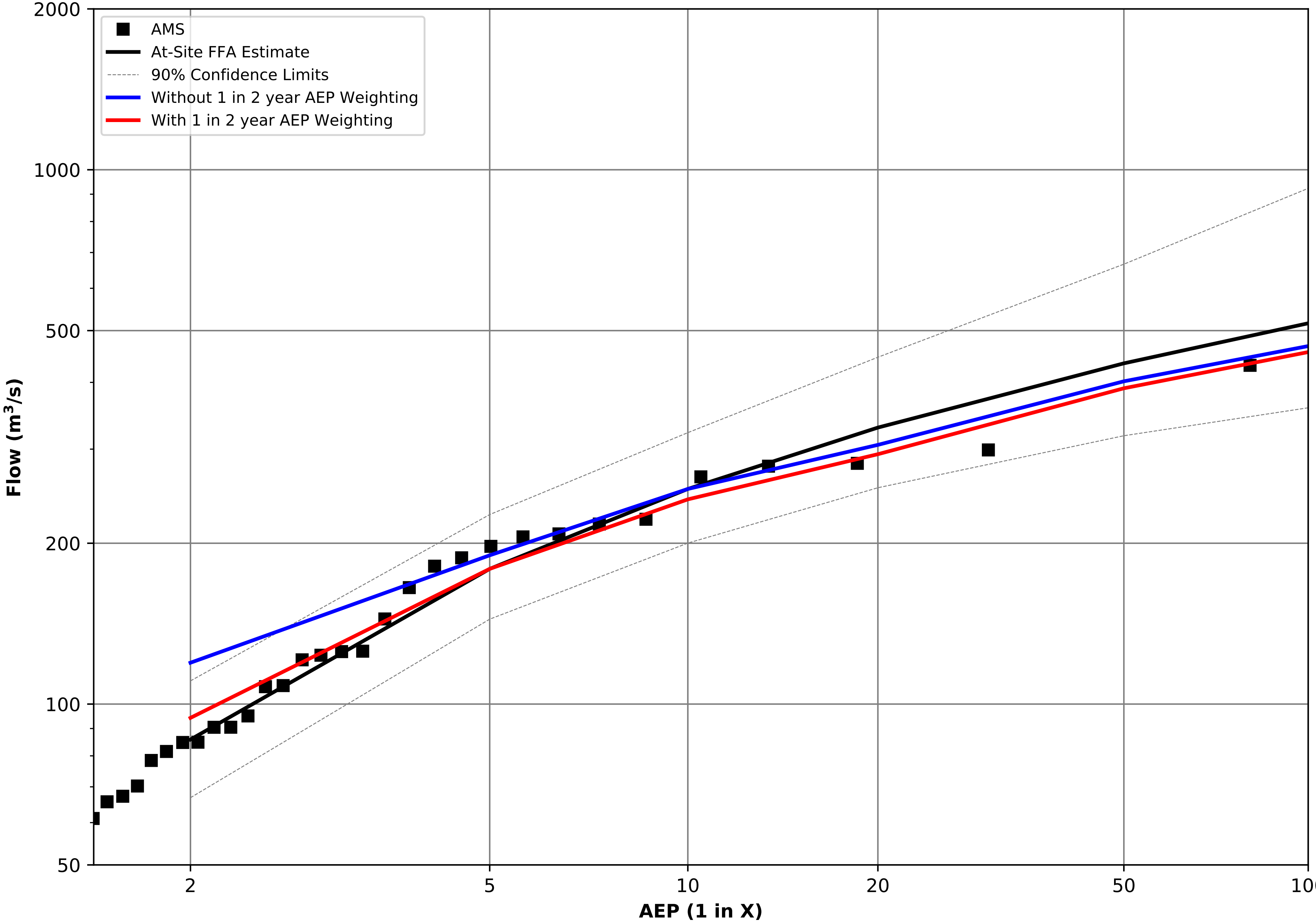
J:\Jobs\118014\PDF\Report\FIGURE14_Cost Weighting Adjustment Before and After.pdf
J:\Jobs\118014\Software\plots\Pdf_Figure_08_10_18_33_Probability_Distribution.py



COST WEIGHTING ADJUSTMENT BEFORE AND AFTER DURRUMBUL (SHERRYS CROSSING) (I28)

FIGURE 14

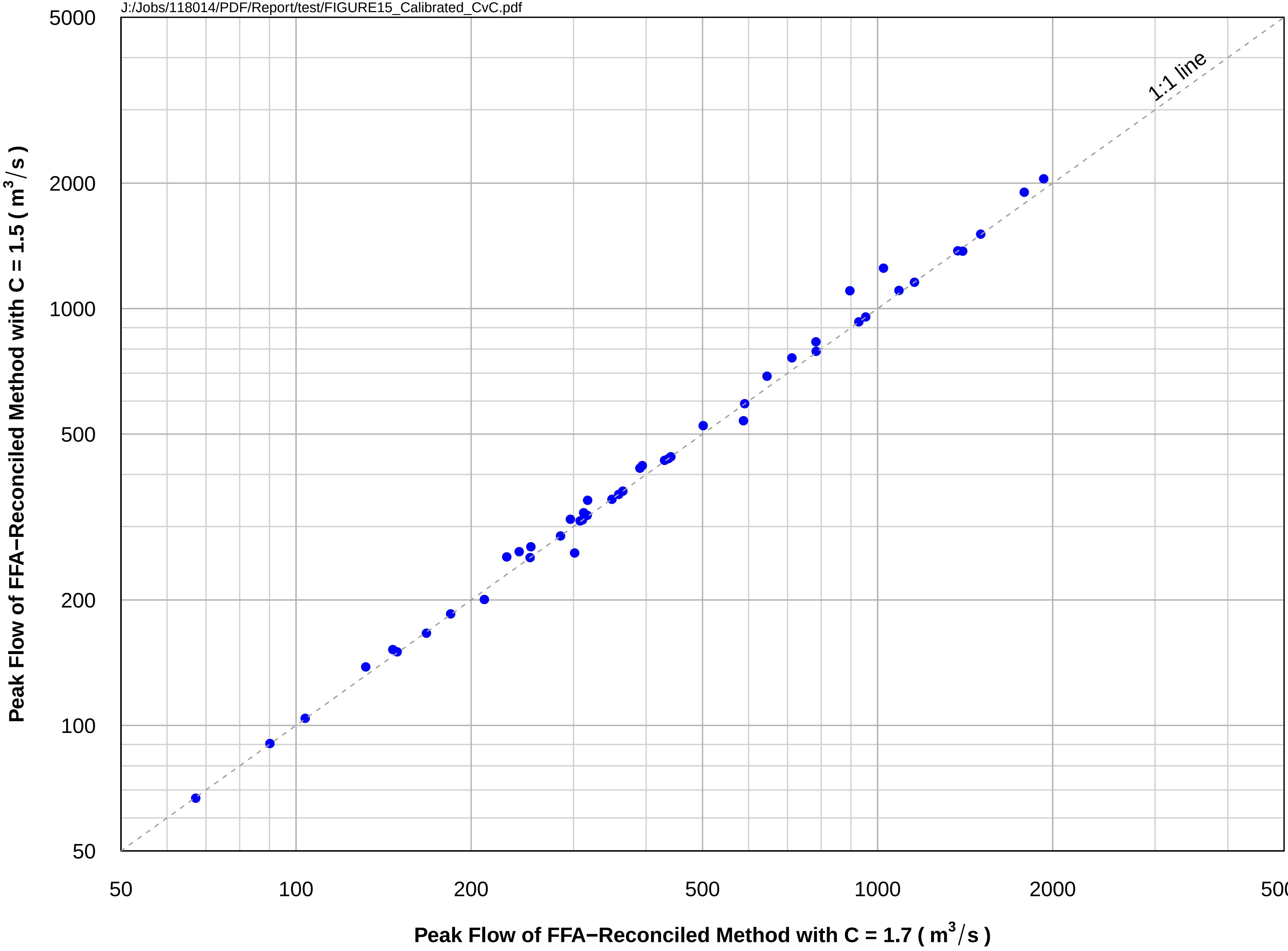


FIGURE 15

FLOW COMPARISON FFA−RECONCILED METHOD 1 IN 10 AEP

CHANGE IN CATCHMENT ROUTING (C=1.7 VS C=1.5)

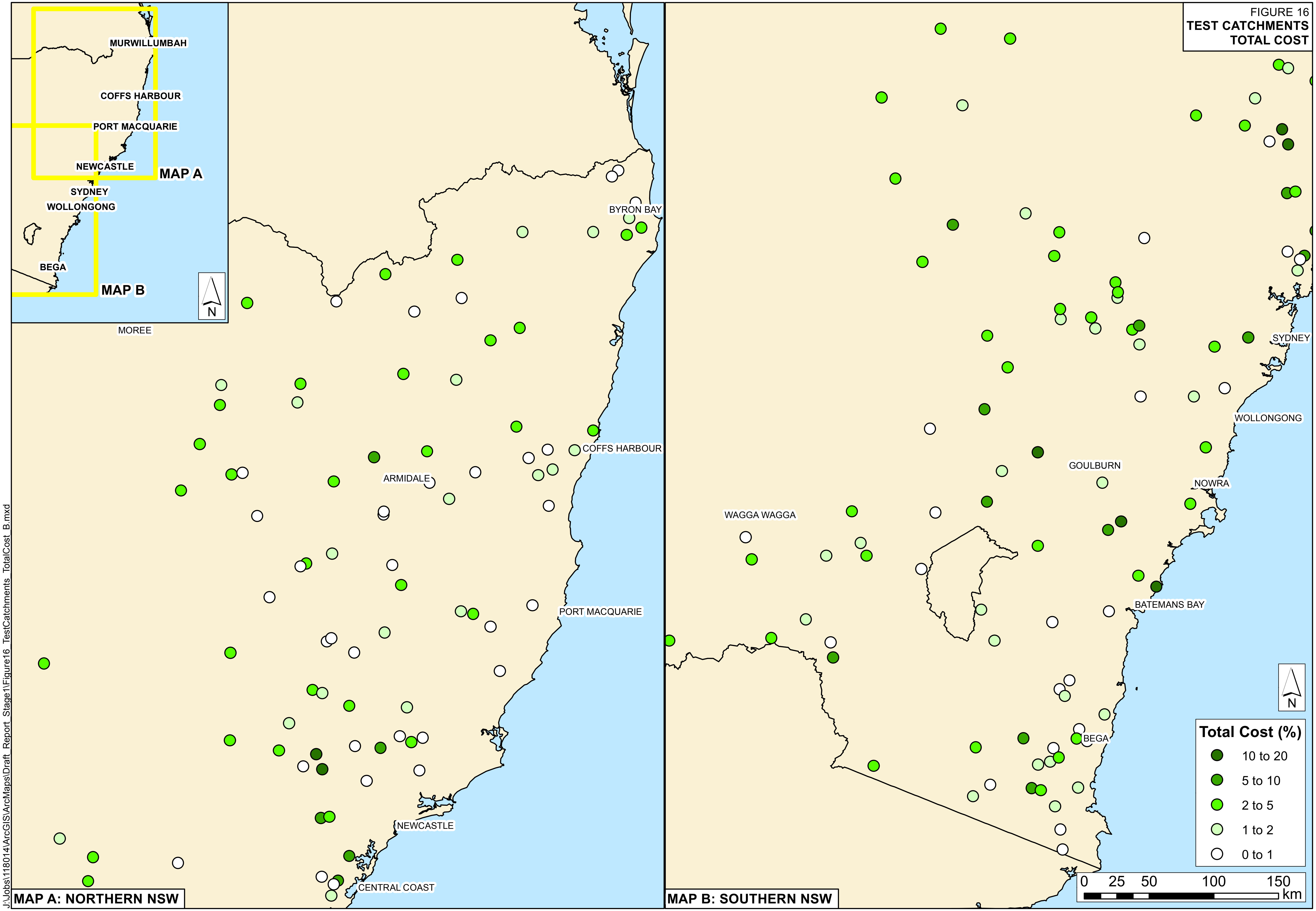


FIGURE 16
TEST CATCHMENTS
TOTAL COST
MURWILLUMBAH
COFFS HARBOUR
PORT MACQUARIE
NEWCASTLE
MAP A
SYDNEY
WOLLONGONG
BEGA
MAP B
N
MOREE
BYRON BAY
ARMIDALE
COFFS HARBOUR
PORT MACQUARIE
NEWCASTLE
CENTRAL COAST
MAP A: NORTHERN NSW
SYDNEY
WOLLONGONG
GOULBURN
NOWRA
WAGGA WAGGA
BATEMANS BAY
BEGA
MAP B: SOUTHERN NSW
Total Cost (%)
10 to 20
5 to 10
2 to 5
1 to 2
0 to 1
0 25 50 100 150
km
J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure16_TestCatchments_TotalCost_B.mxd

J:\Jobs\118014\PDF\Report\FIGURE17_Typical Calibration with Gradient Understimation.pdf
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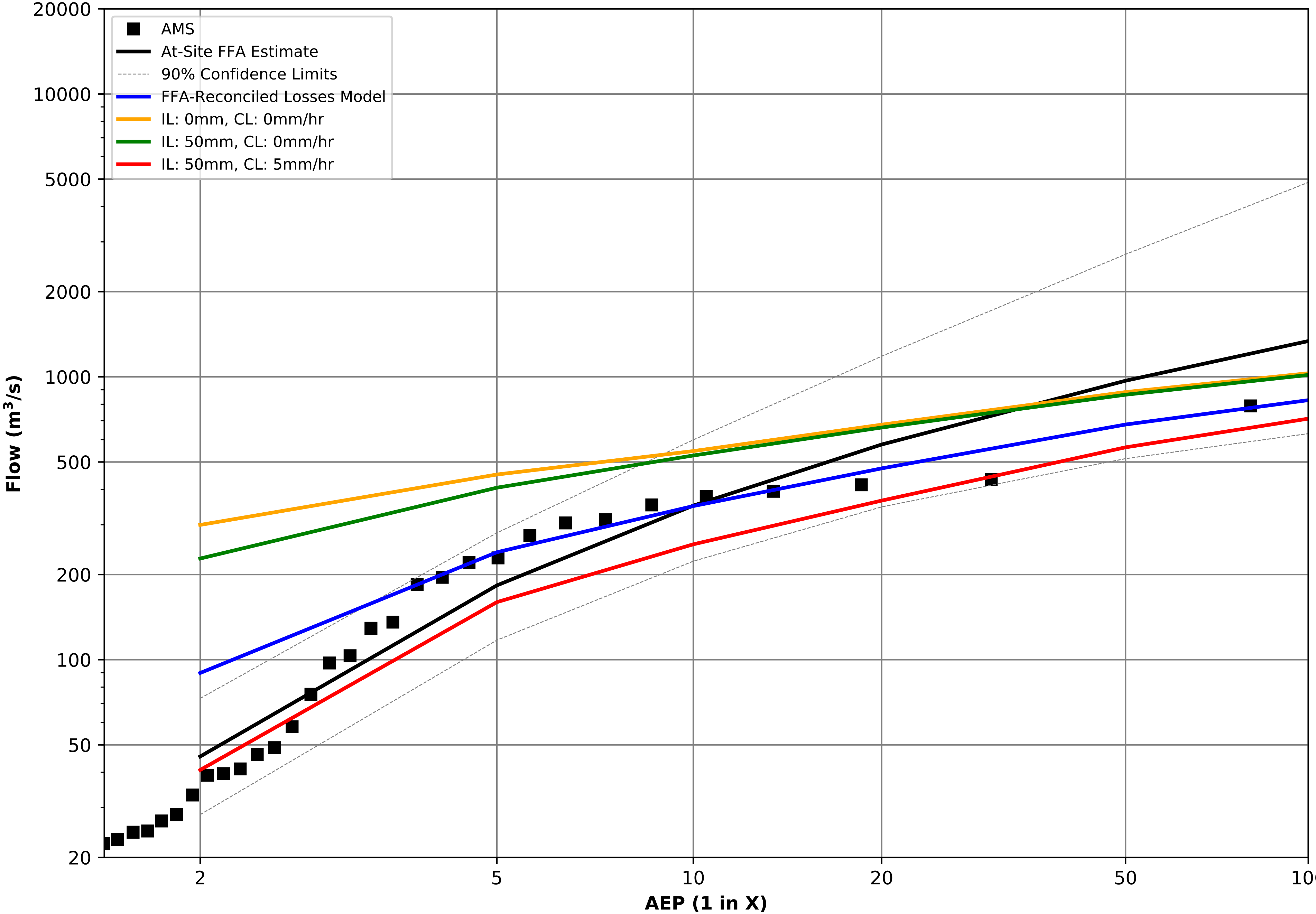


TYPICAL CALIBRATION WITH GRADIENT UNDERSTIMATION
CANDELO DAM SITE (A7)

FIGURE 17

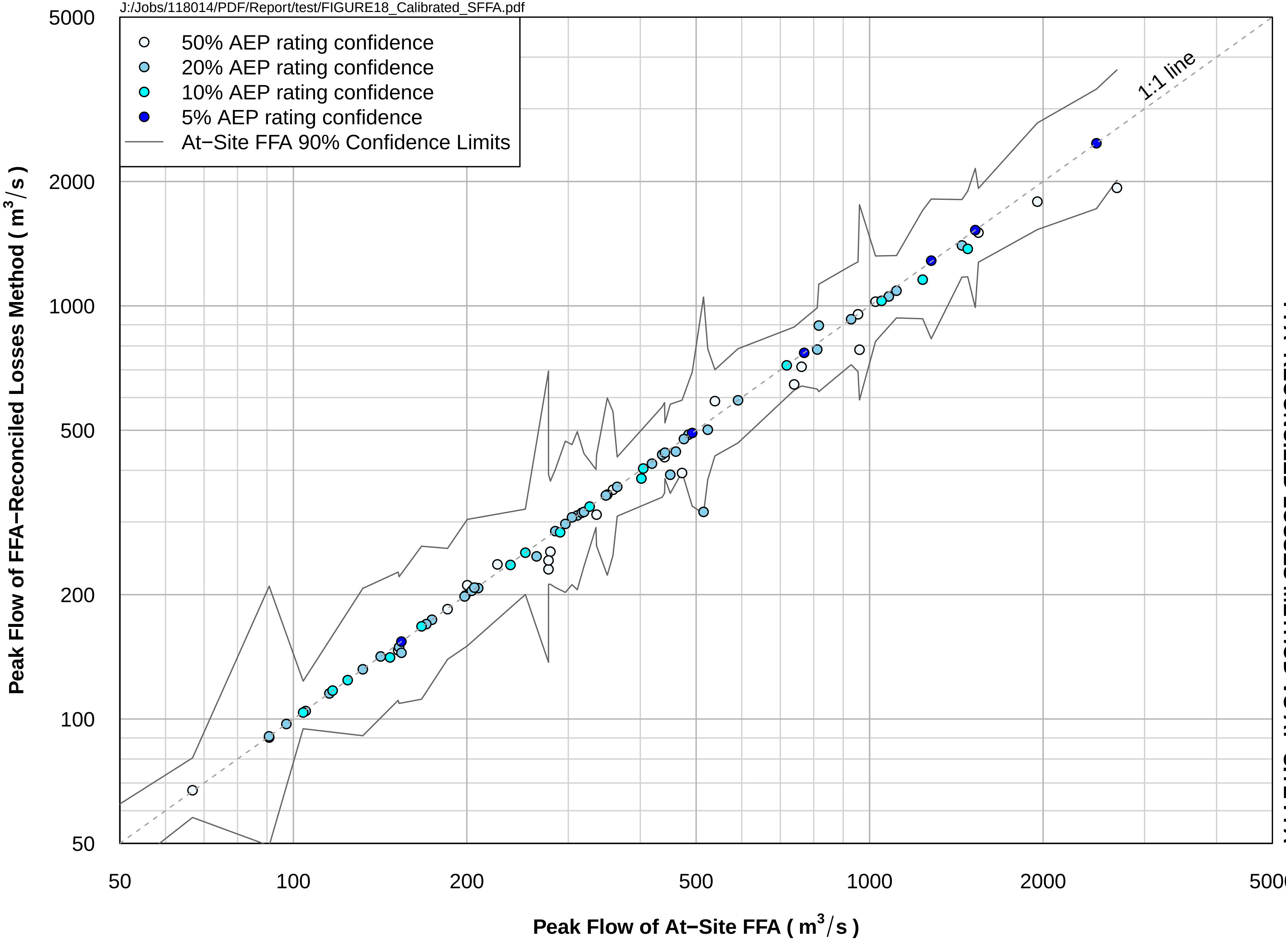


FIGURE 18
FLOW COMPARISON 1 IN 10 AEP
FFA−RECONCILED LOSSES METHOD VS AT−SITE FFA

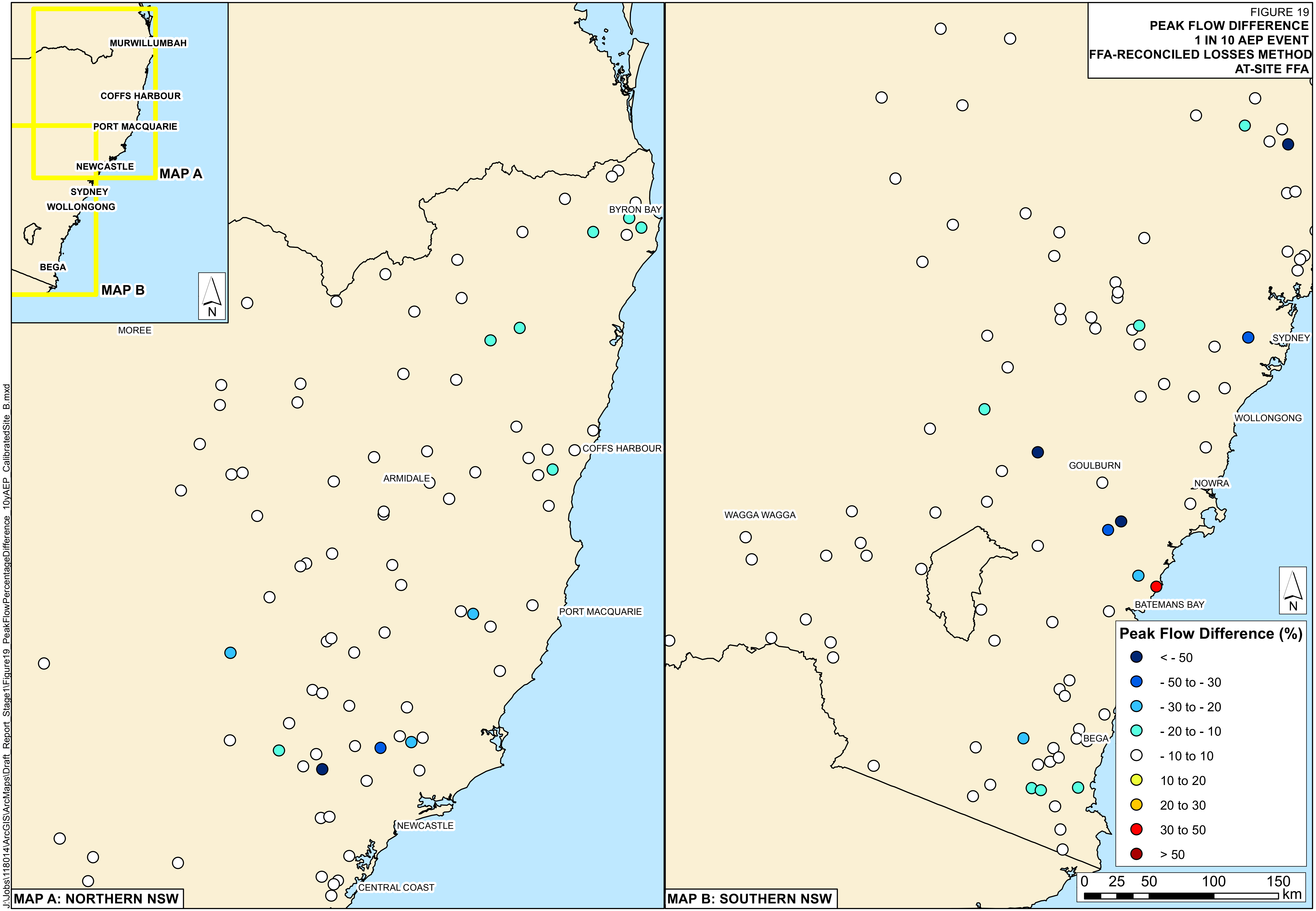


FIGURE 19
PEAK FLOW DIFFERENCE
1 IN 10 AEP EVENT
FFA-RECONCILED LOSSES METHOD
AT-SITE FFA

J:\Jobs\118014\ArcGIS\ArcMaps\Draft Report Stage1\Figure19 PeakFlowPercentageDifference 10yAEP CalibratedSite B.mxd

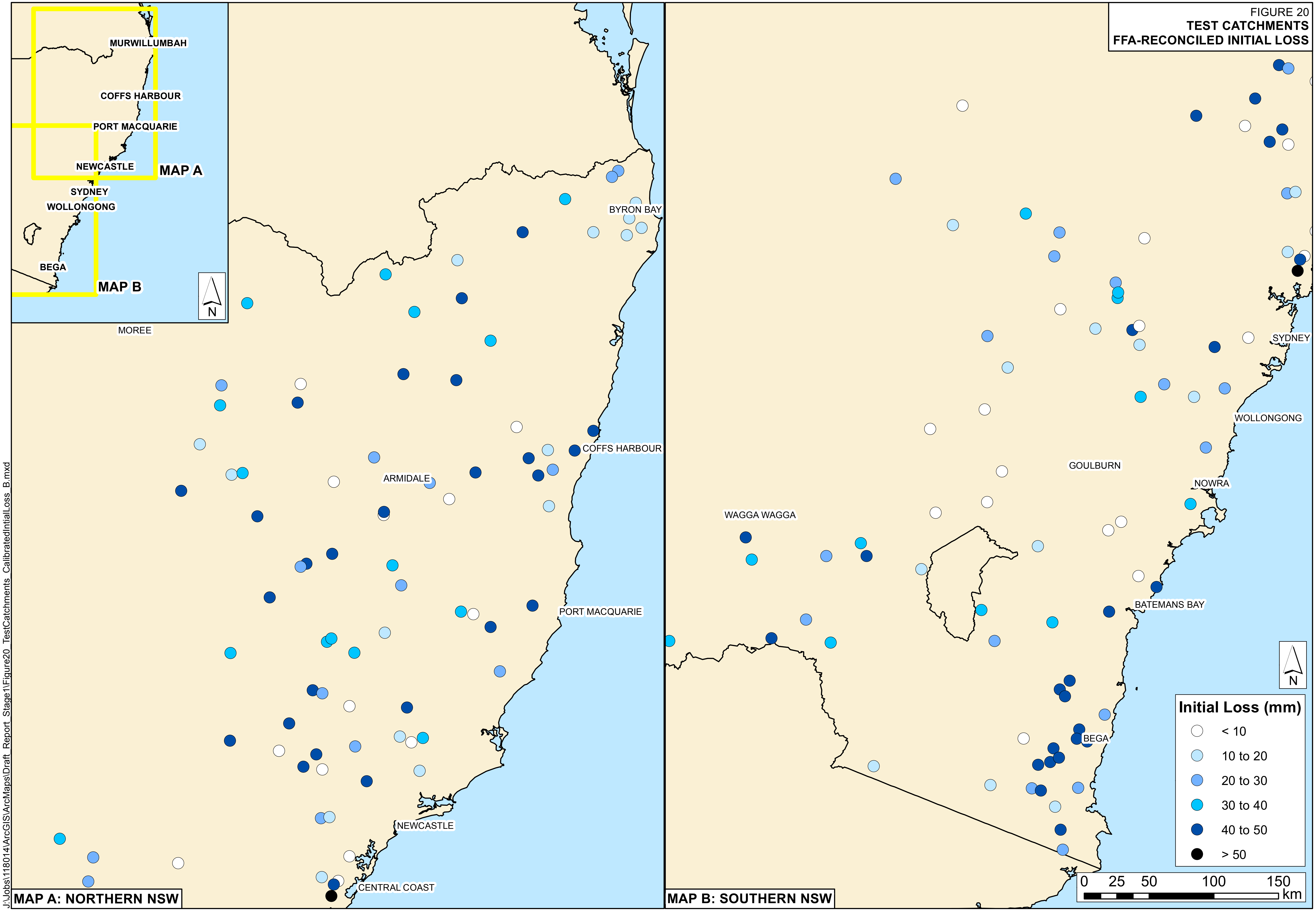


FIGURE 20
TEST CATCHMENTS
FFA-RECONCILED INITIAL LOSS

J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure20_TestCatchments_CalibratedInitialLoss_B.mxd

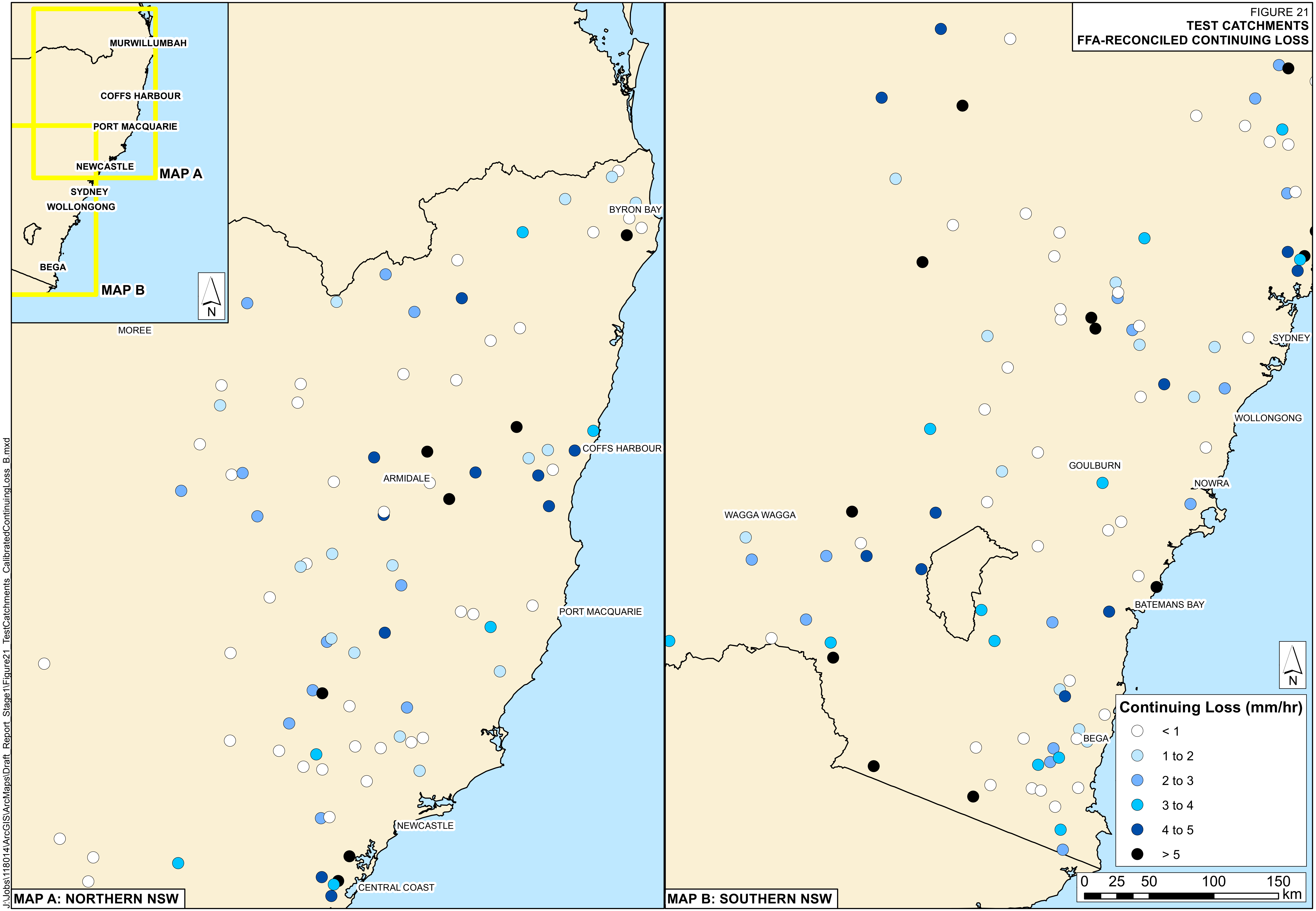
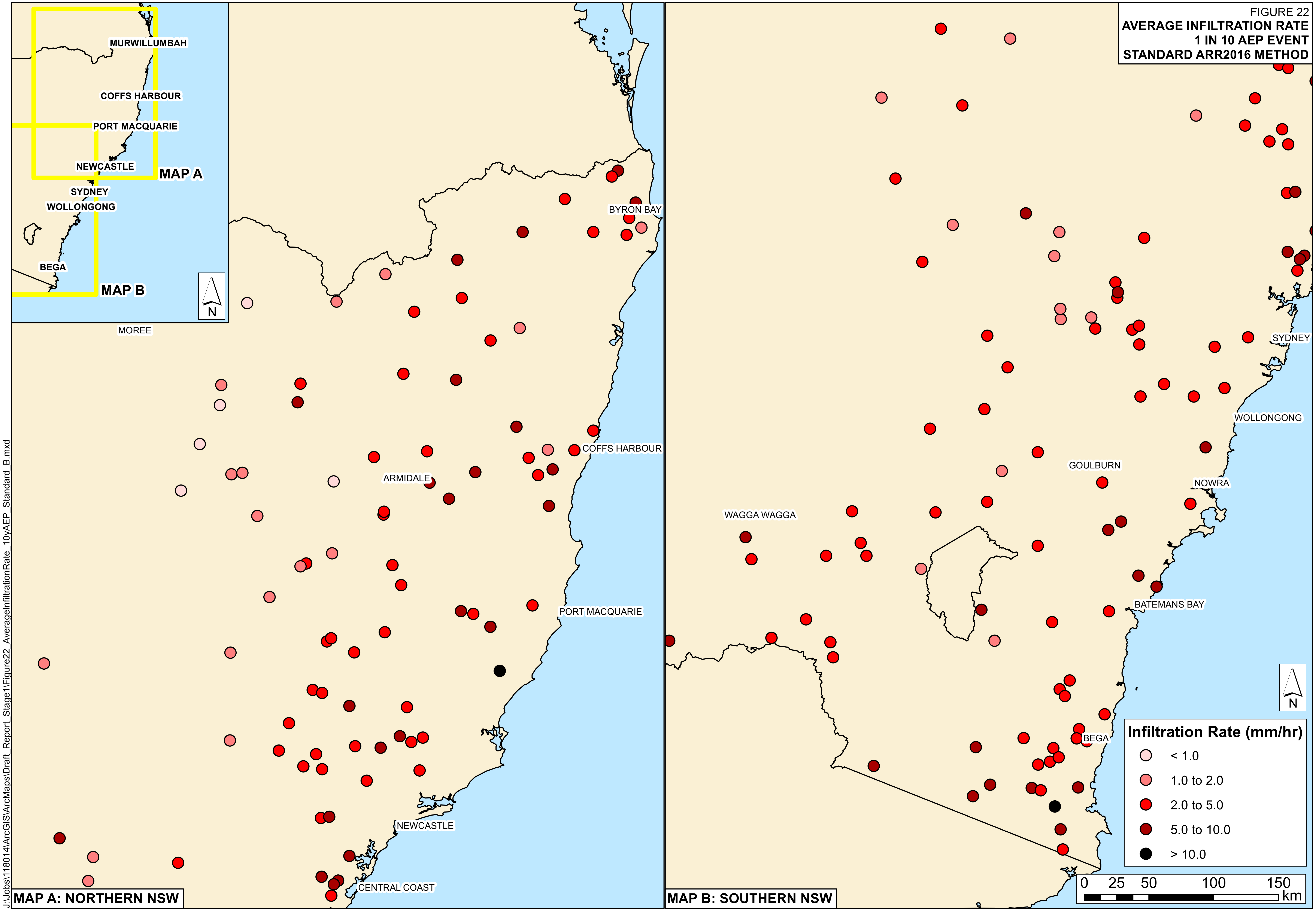


FIGURE 21
TEST CATCHMENTS
FFA-RECONCILED CONTINUING LOSS

J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure21_TestCatchments_CalibratedContinuingLoss_B.mxd



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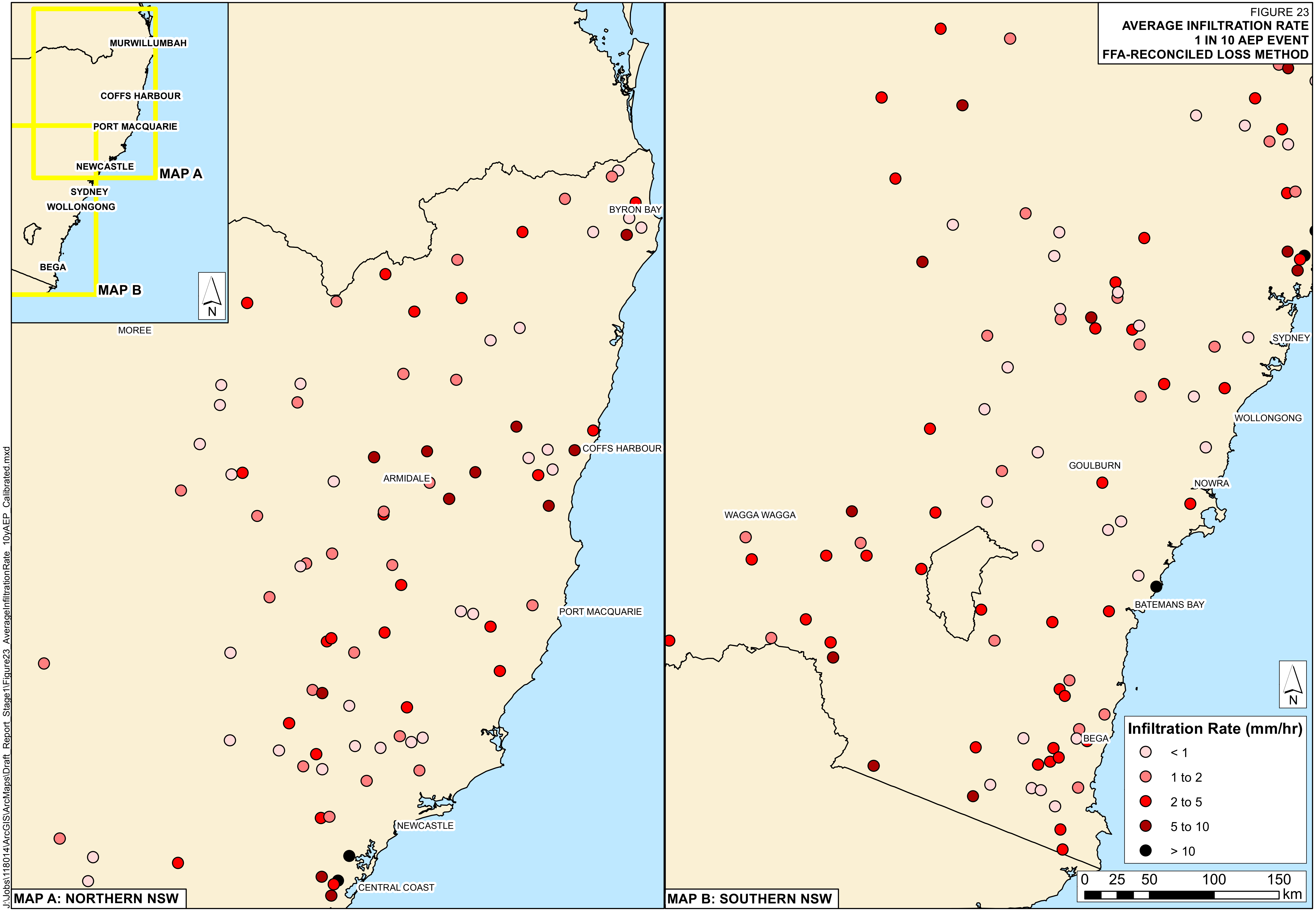

FIGURE 23
AVERAGE INFILTRATION RATE
1 IN 10 AEP EVENT
FFA-RECONCILED LOSS METHOD

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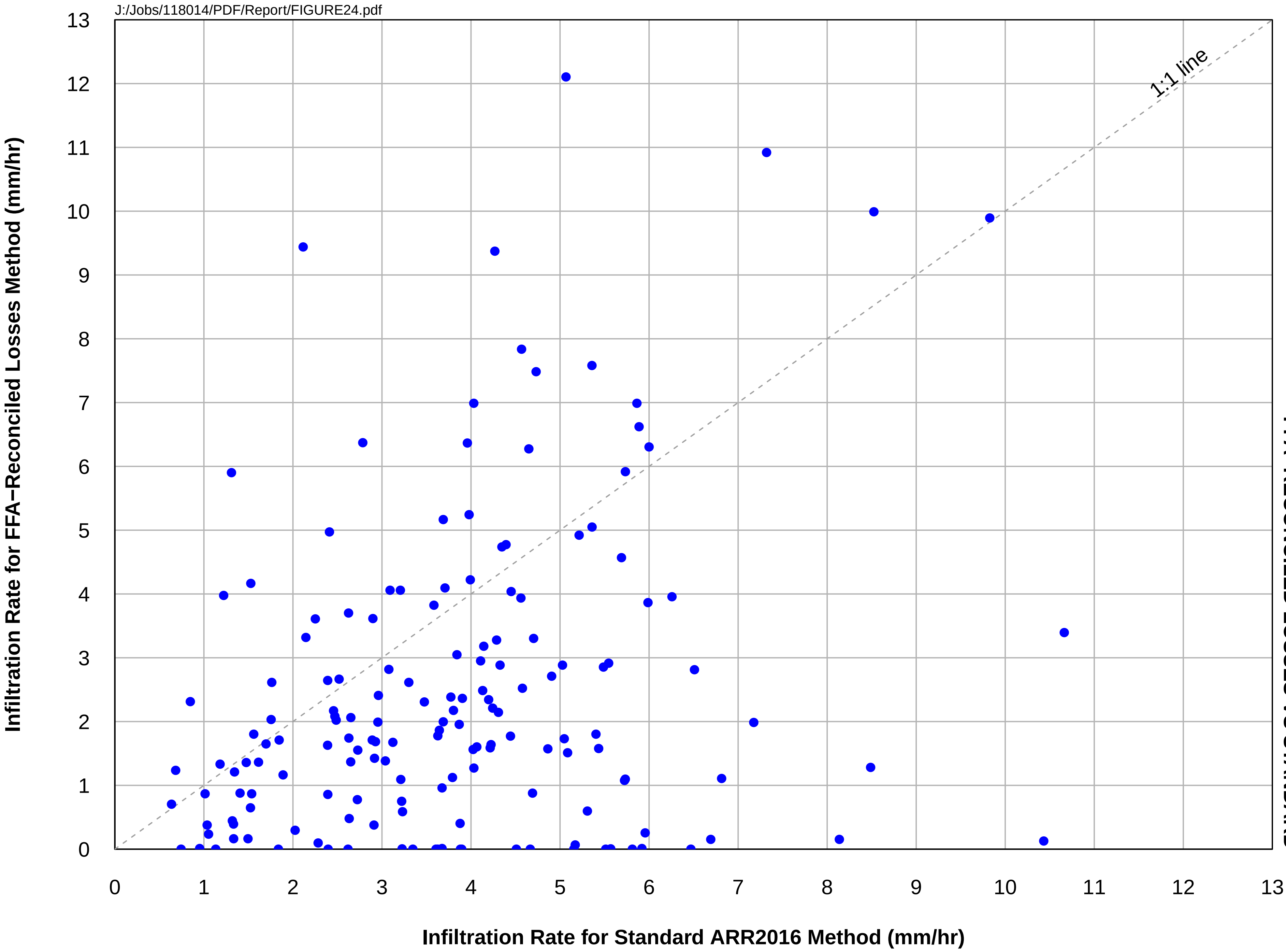

FIGURE 24
INFILTRATION RATE FOR THE 1 IN 10 AEP FFA−RECONCILED LOSSES VS STANDARD

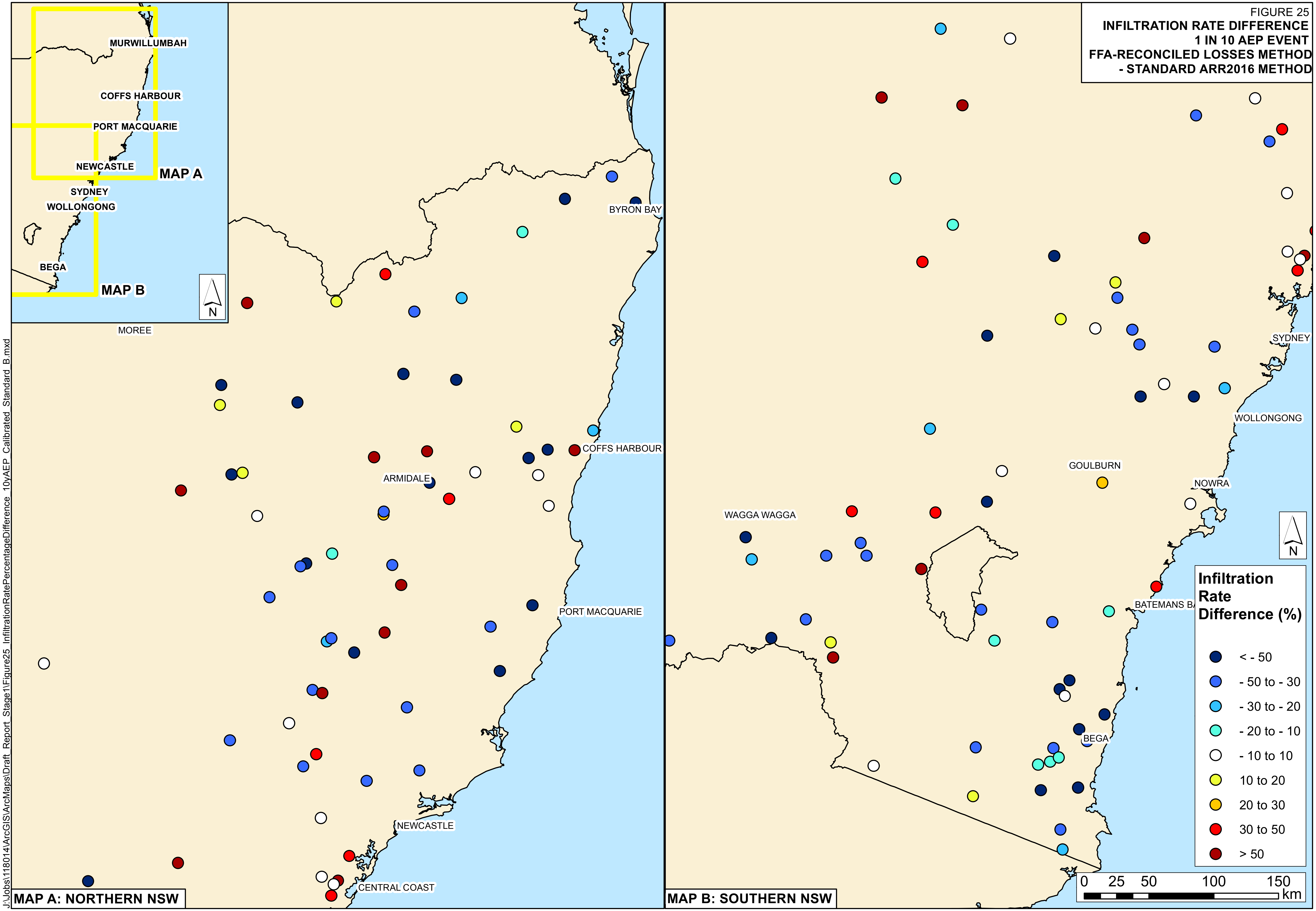

FIGURE 25
INFILTRATION RATE DIFFERENCE
1 IN 10 AEP EVENT
FFA-RECONCILED LOSSES METHOD
- STANDARD ARR2016 METHOD
MURWILLUMBAH
COFFS HARBOUR
PORT MACQUARIE
NEWCASTLE
MAP A
SYDNEY
WOLLONGONG
BEGA
MAP B
N
MOREE
BYRON BAY
ARMIDALE
COFFS HARBOUR
PORT MACQUARIE
NEWCASTLE
CENTRAL COAST
MAP A: NORTHERN NSW
SYDNEY
WOLLONGONG
GOULBURN
NOWRA
WAGGA WAGGA
BATEMANS BA
BEGA
MAP B: SOUTHERN NSW
Infiltration Rate Difference (%)
< - 50
- 50 to - 30
- 30 to - 20
- 20 to - 10
- 10 to 10
10 to 20
20 to 30
30 to 50
> 50
0 25 50 100 150
km
J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure25_InfiltrationRatePercentageDifference_10yAEP_Calibrated_Standard_B.mxd

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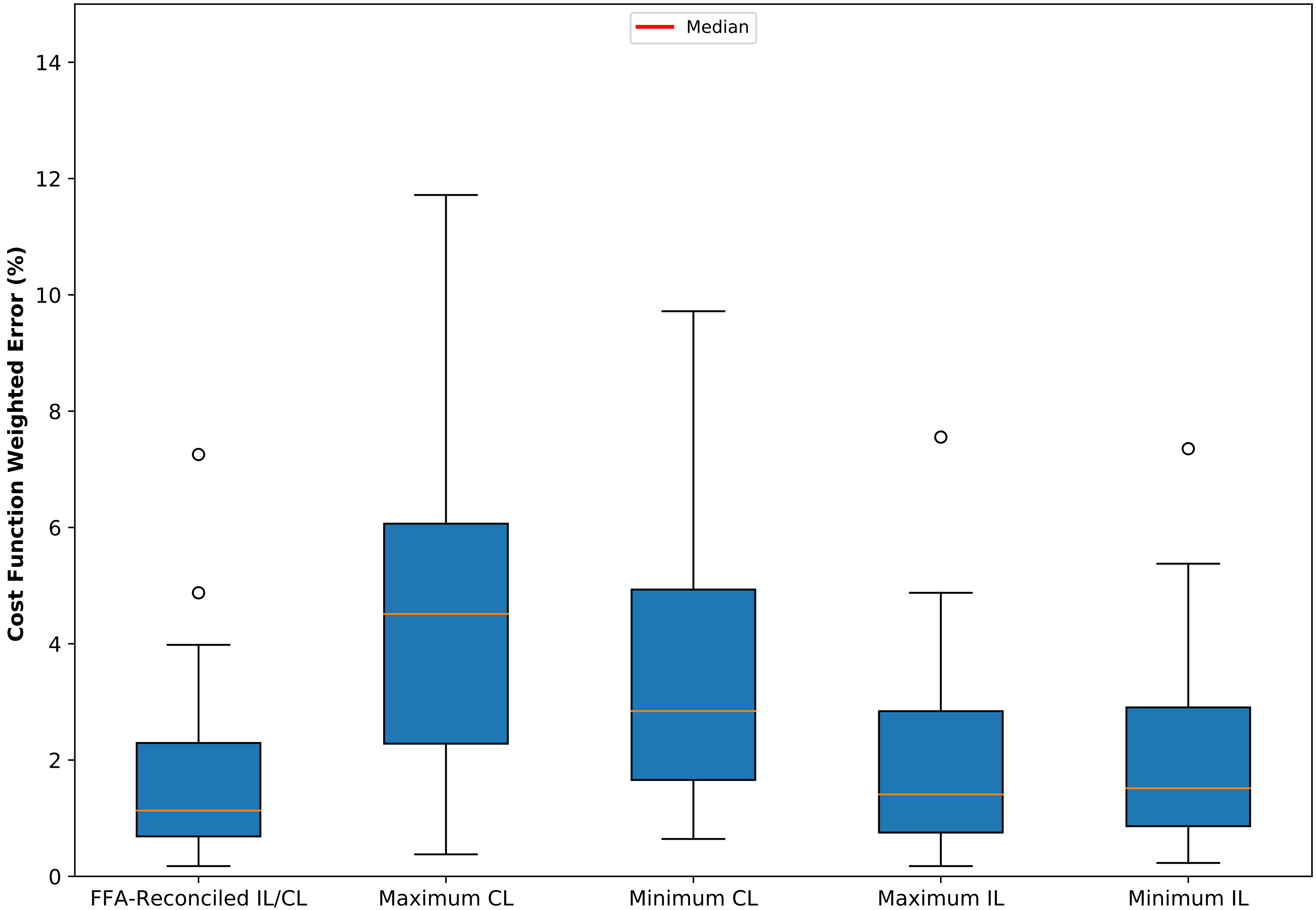


FIGURE 26

COSTS OF FIXED LOSSES EXTREME VALUES

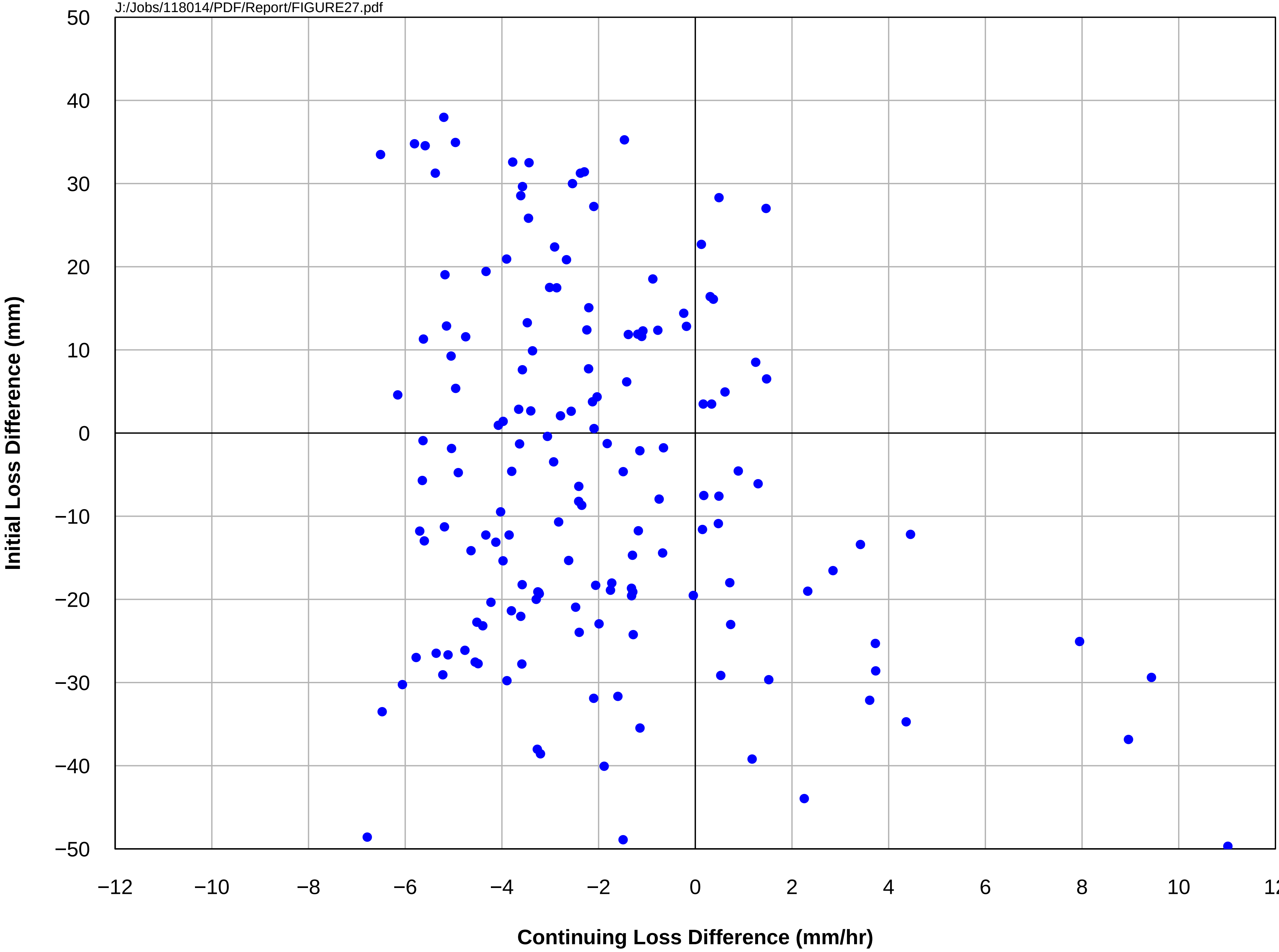


FIGURE 27
FFA−RECONCILED – STANDARD INITIAL LOSS VS
FFA−RECONCILED – STANDARD CONTINUING LOSS

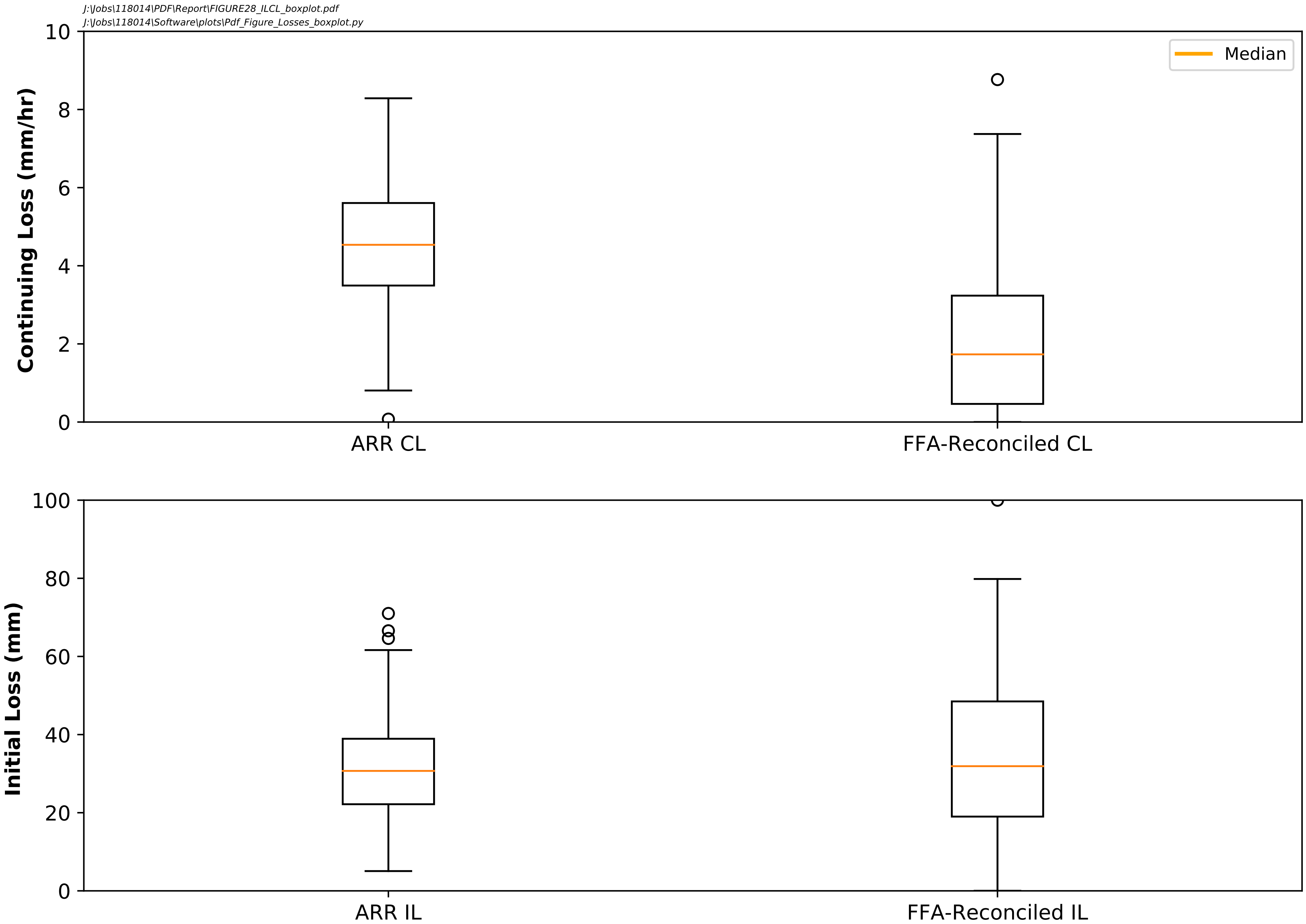
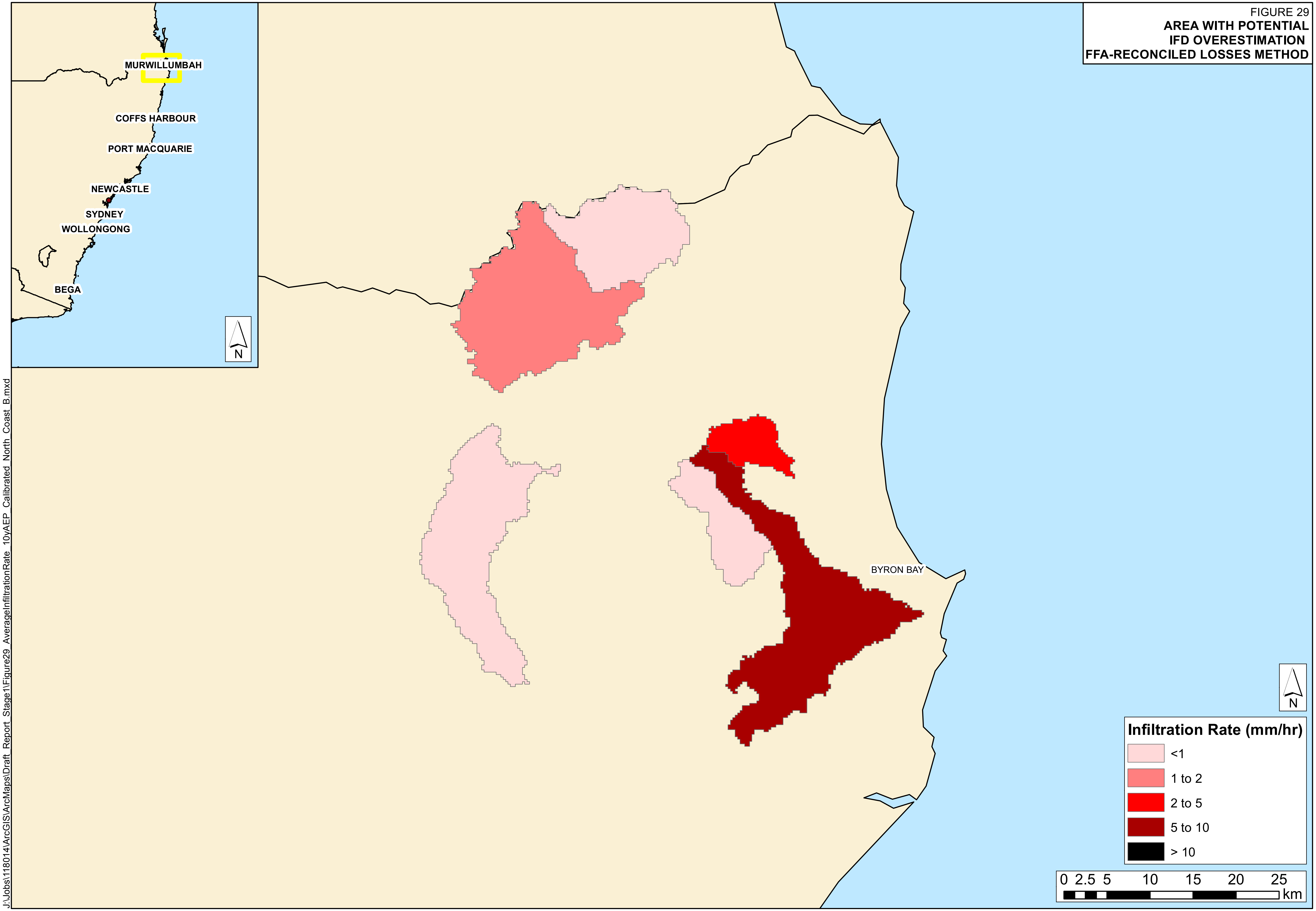


FIGURE 28

FFA-RECONCILED LOSSES VS ARR2016 INITIAL AND CONTINUING LOSS



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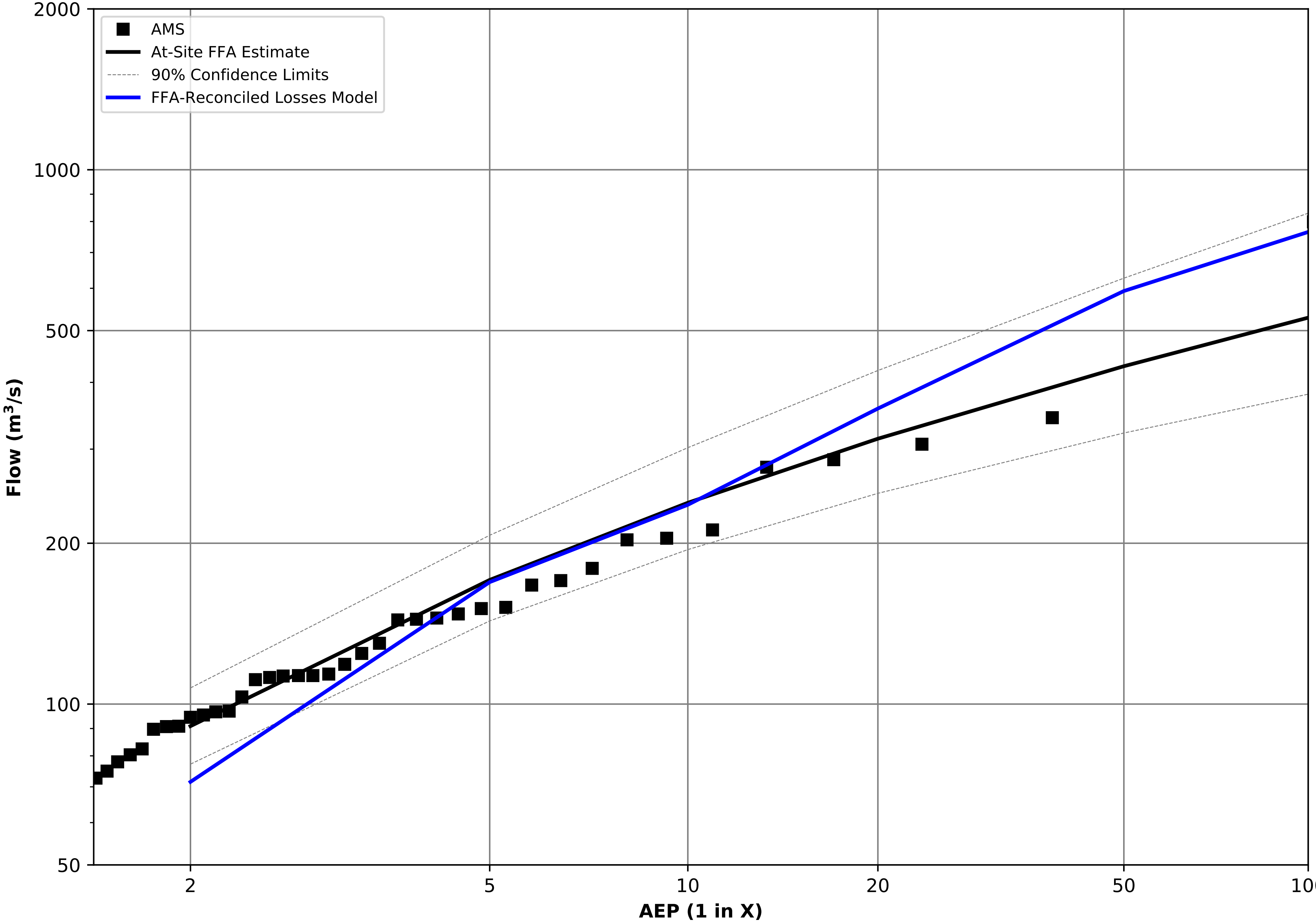


SITE NEEDING TEMPORAL PATTERN BIN SMOOTHING
LACMALAC (E10)

FIGURE 30

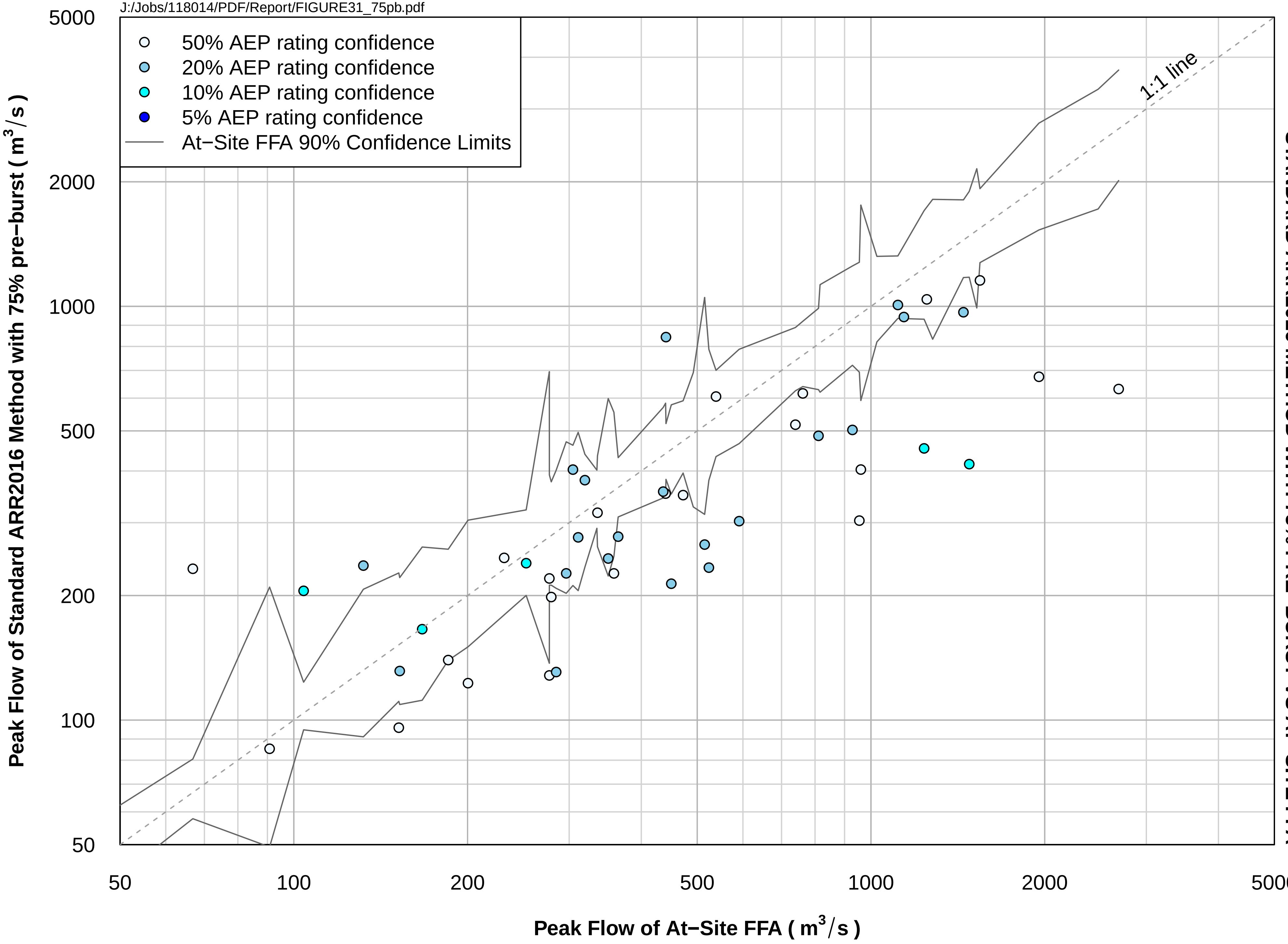


FIGURE 31
FLOW COMPARISON 1 IN 10 AEP
STANDARD ARR2016 METHOD WITH 75% PRE−BURST VS AT−SITE FFA

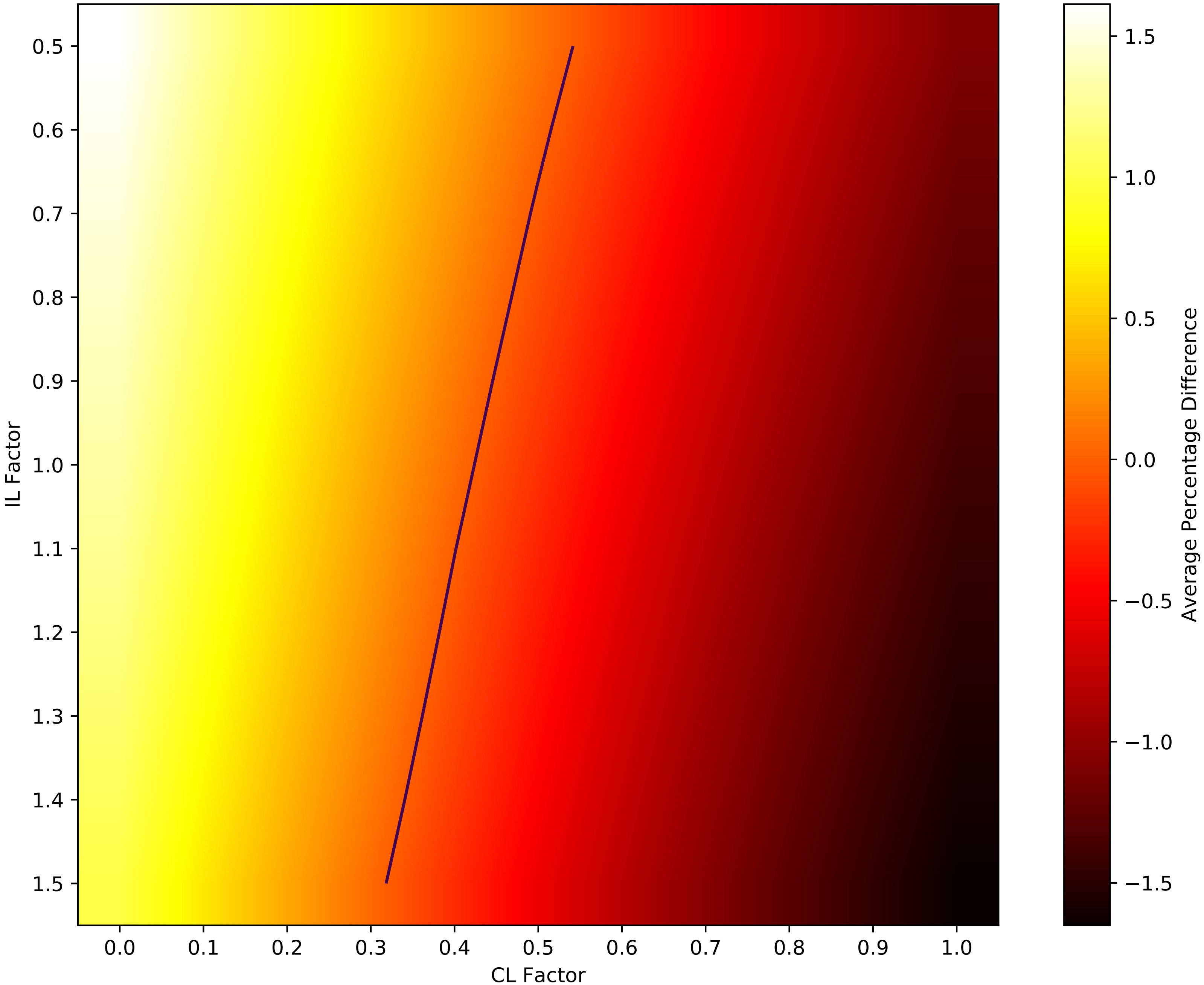


FIGURE 32

AVERAGE PERCENTAGE DIFFERENCE FOR INITIAL AND CONTINUING LOSS ADJUSTMENT FACTORS 1 IN 10 AEP

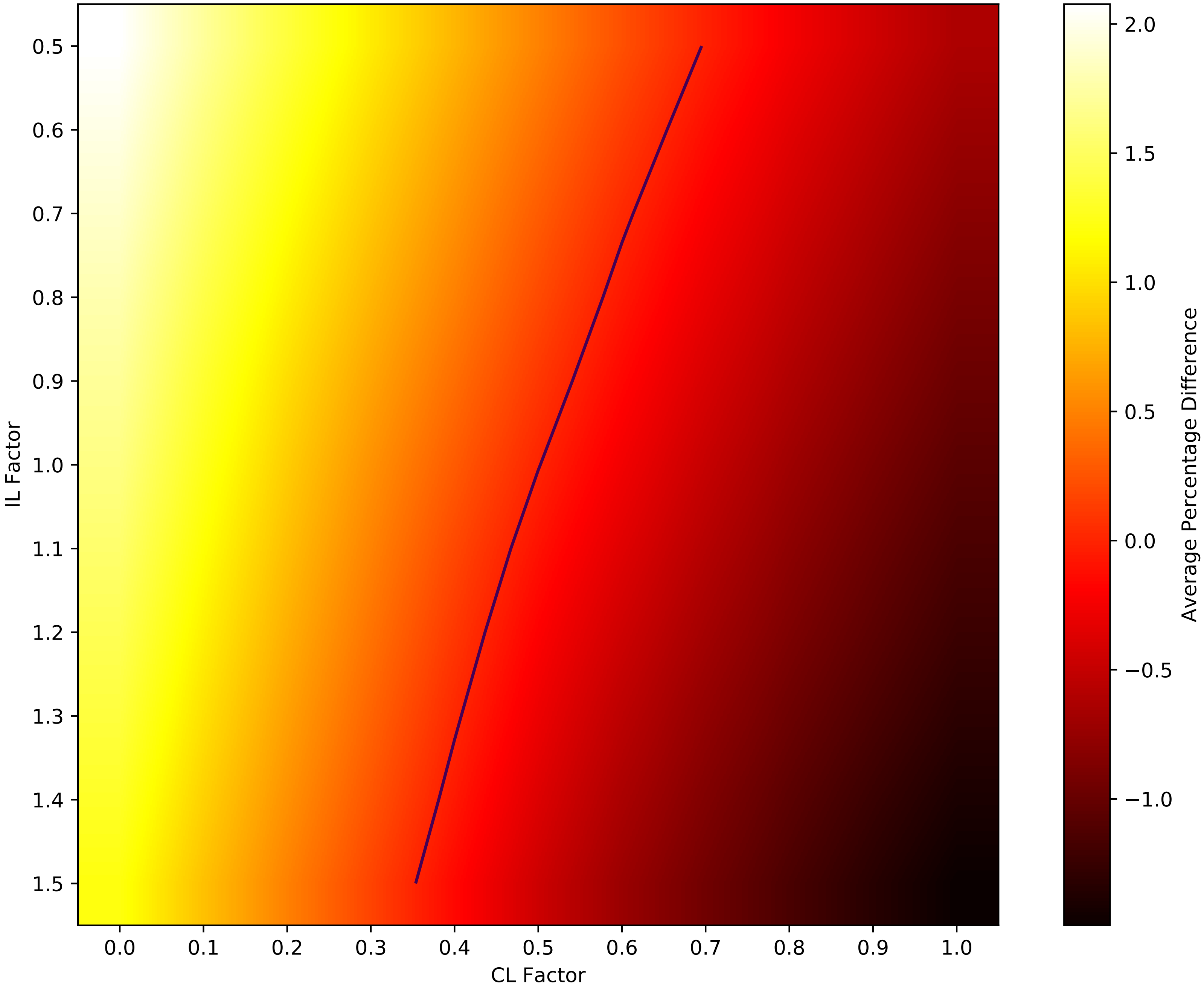


FIGURE 33

AVERAGE PERCENTAGE DIFFERENCE FOR INITIAL AND CONTINUING LOSS ADJUSTMENT FACTORS 1 IN 10 AEP EAST GREAT DIVIDING RANGE

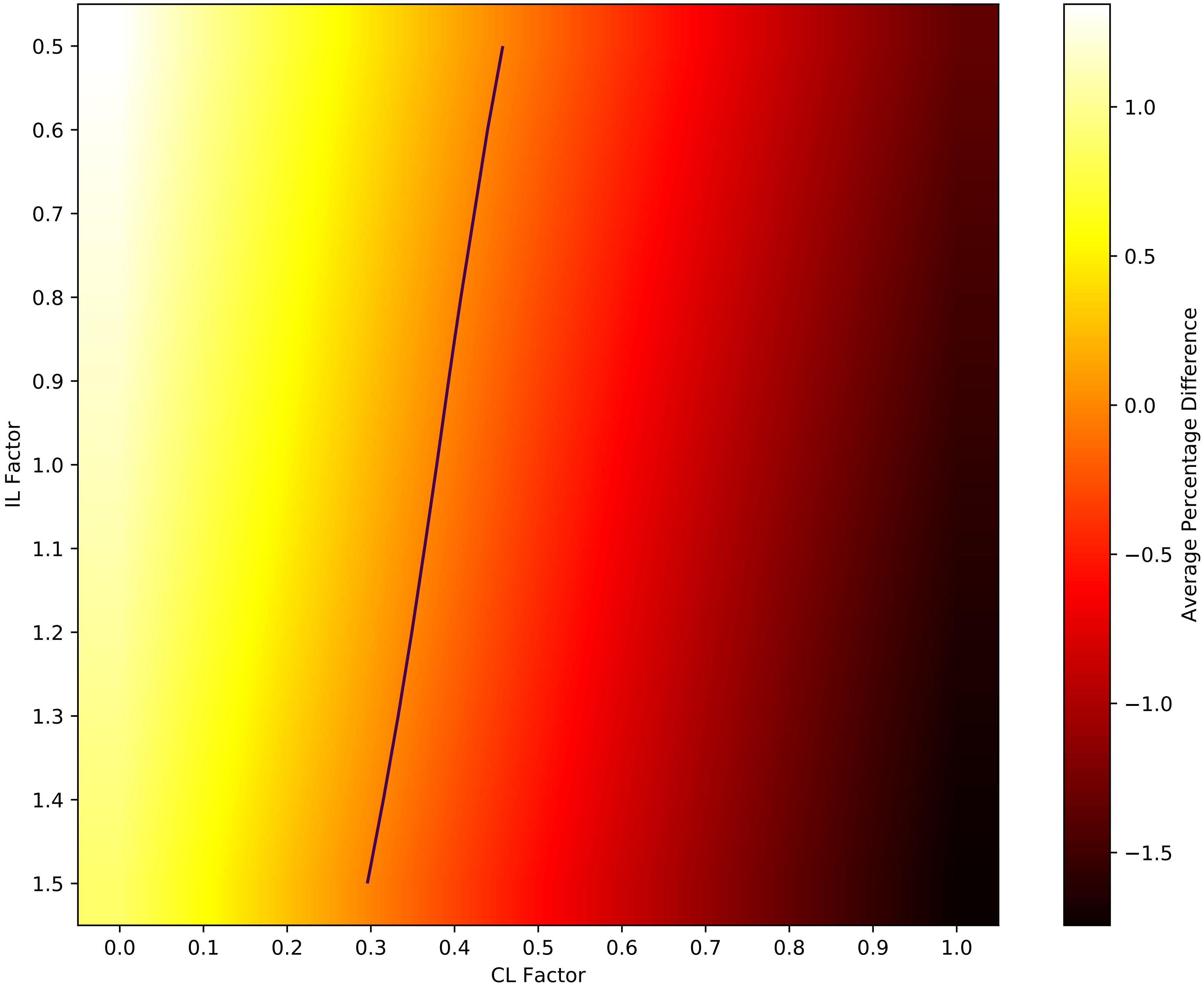


FIGURE 34

AVERAGE PERCENTAGE DIFFERENCE FOR INITIAL AND CONTINUING LOSS ADJUSTMENT FACTORS 1 IN 10 AEP WEST GREAT DIVIDING RANGE

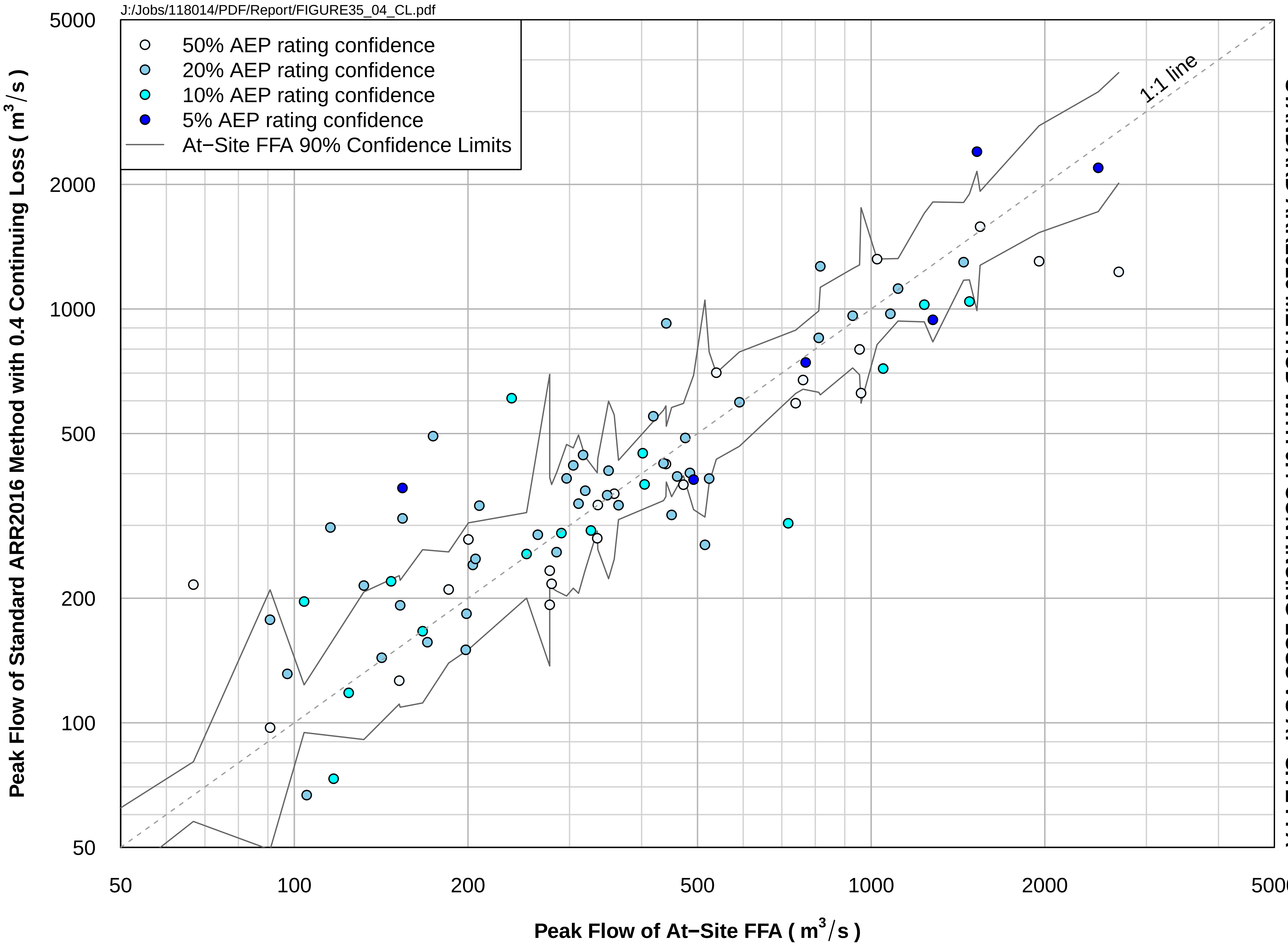
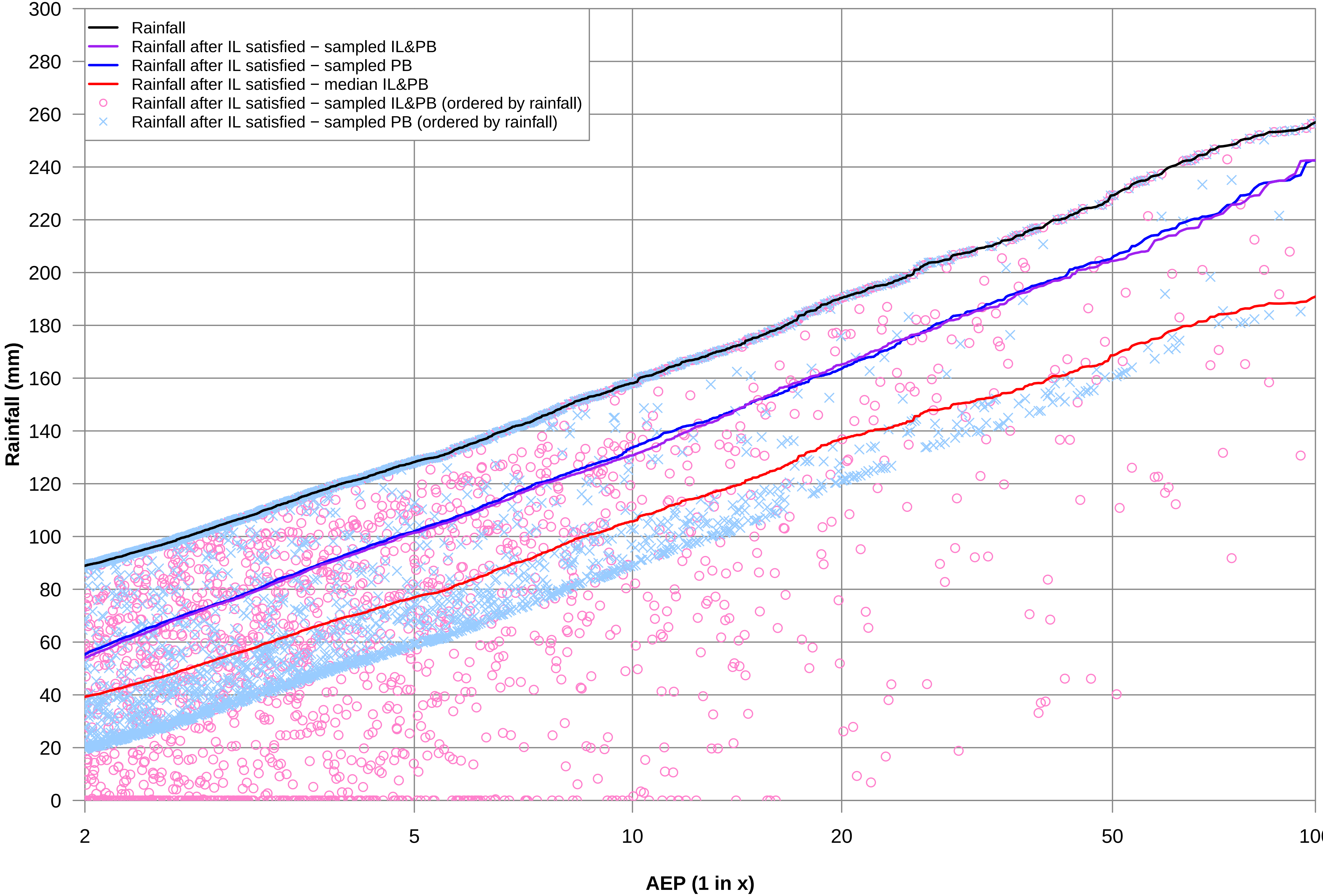


FIGURE 35
FLOW COMPARISON 1 IN 10 AEP
STANDARD ARR2016 METHOD WITH 0.4 CONTINUING LOSS VS AT−SITE FFA

ILLAWARRA REGION RAINFALL AFTER IL SATISFIED METHOD COMPARISON
6 HOUR DURATION



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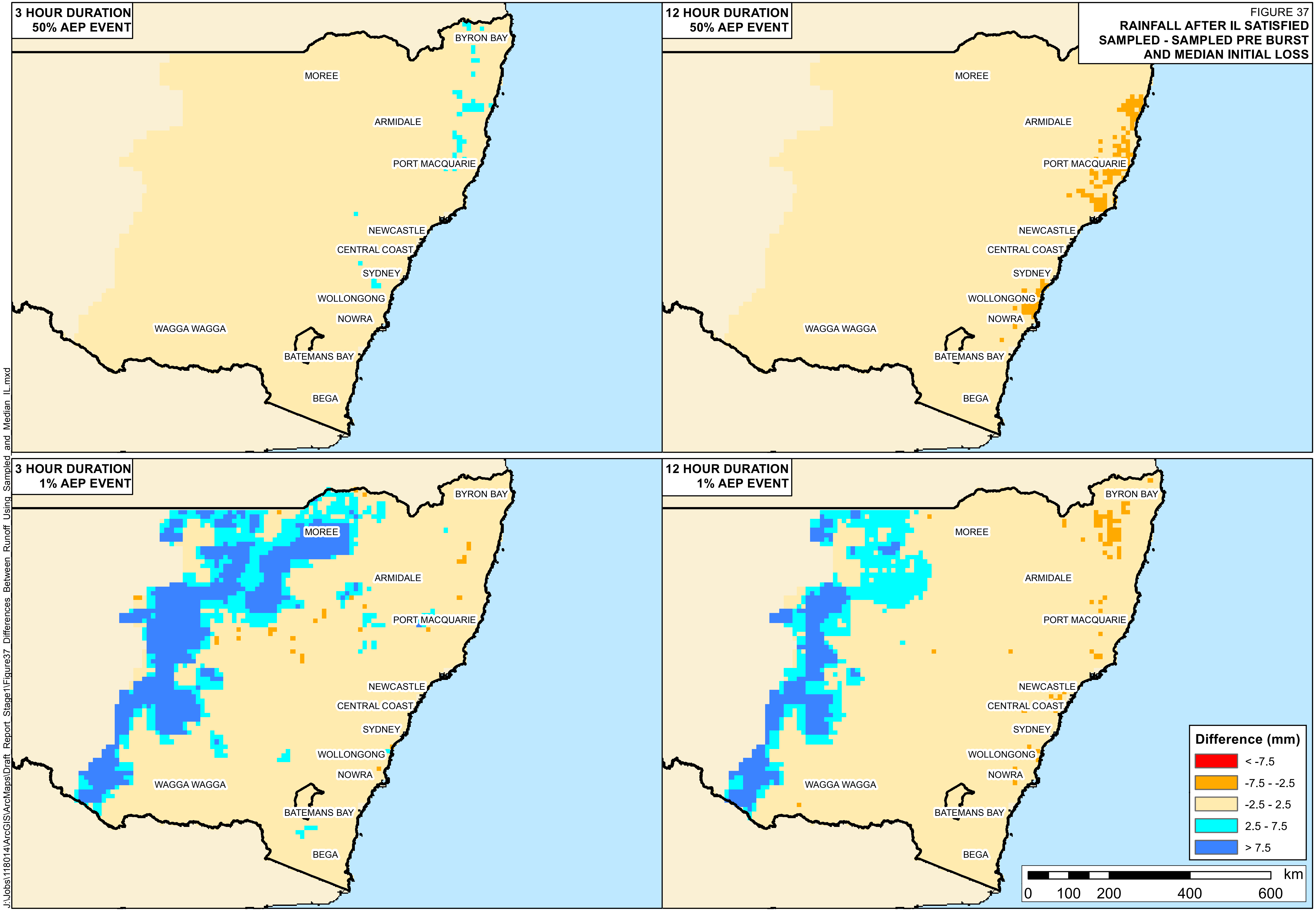
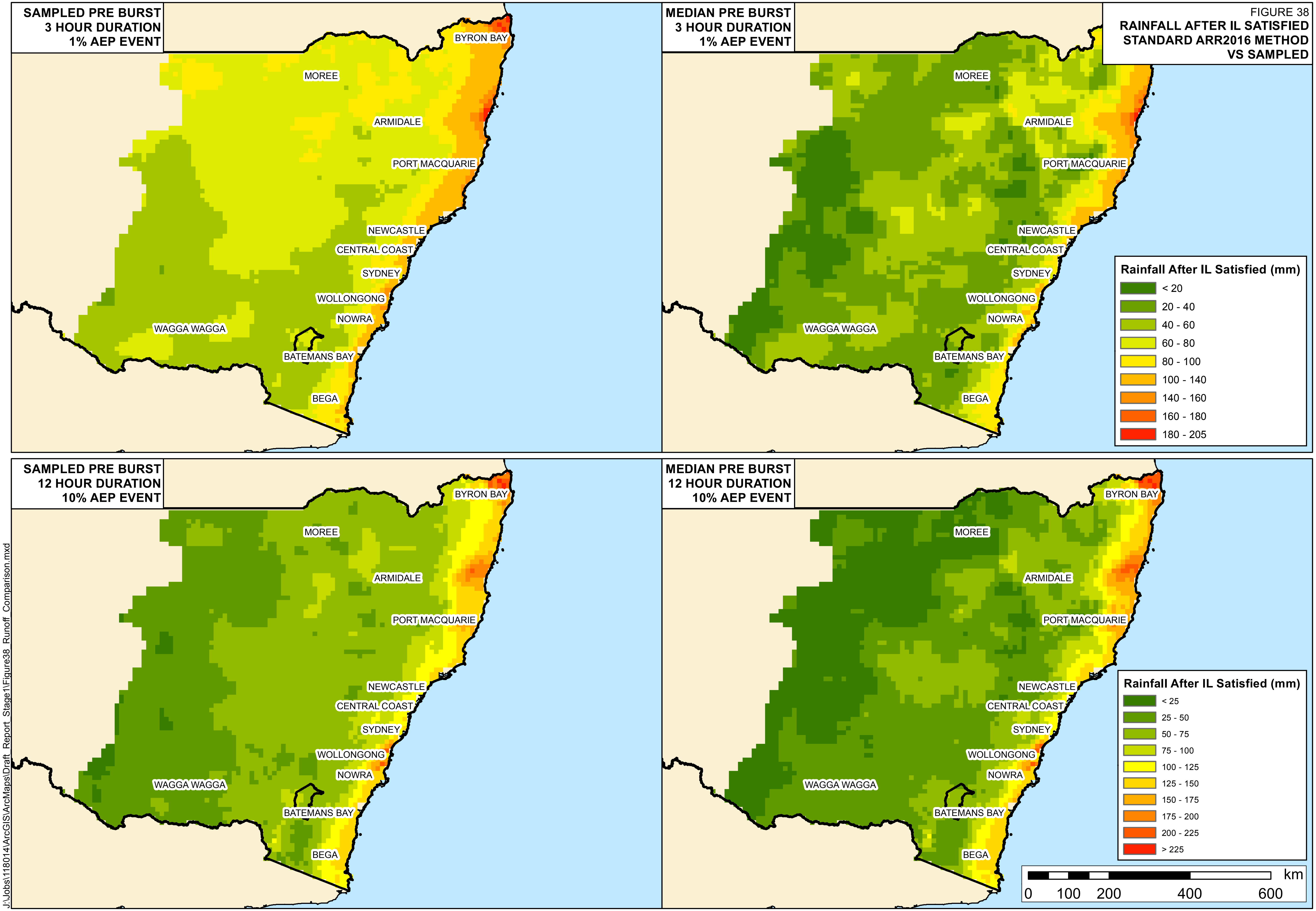


FIGURE 37
RAINFALL AFTER IL SATISFIED
SAMPLED - SAMPLED PRE BURST
AND MEDIAN INITIAL LOSS
3 HOUR DURATION
50% AEP EVENT
12 HOUR DURATION
50% AEP EVENT
3 HOUR DURATION
1% AEP EVENT
12 HOUR DURATION
1% AEP EVENT
BYRON BAY
MOREE
ARMIDALE
PORT MACQUARIE
NEWCASTLE
CENTRAL COAST
SYDNEY
WOLLONGONG
NOWRA
WAGGA WAGGA
BATEMANS BAY
BEGA
Difference (mm)
< -7.5
-7.5 - -2.5
-2.5 - 2.5
2.5 - 7.5
> 7.5
km
0
100
200
400
600
J:\Jobs\118014\ArcGIS\ArcMaps\Draft Report Stage1\Figure37 Differences Between Runoff Using Sampled and Median IL.mxd



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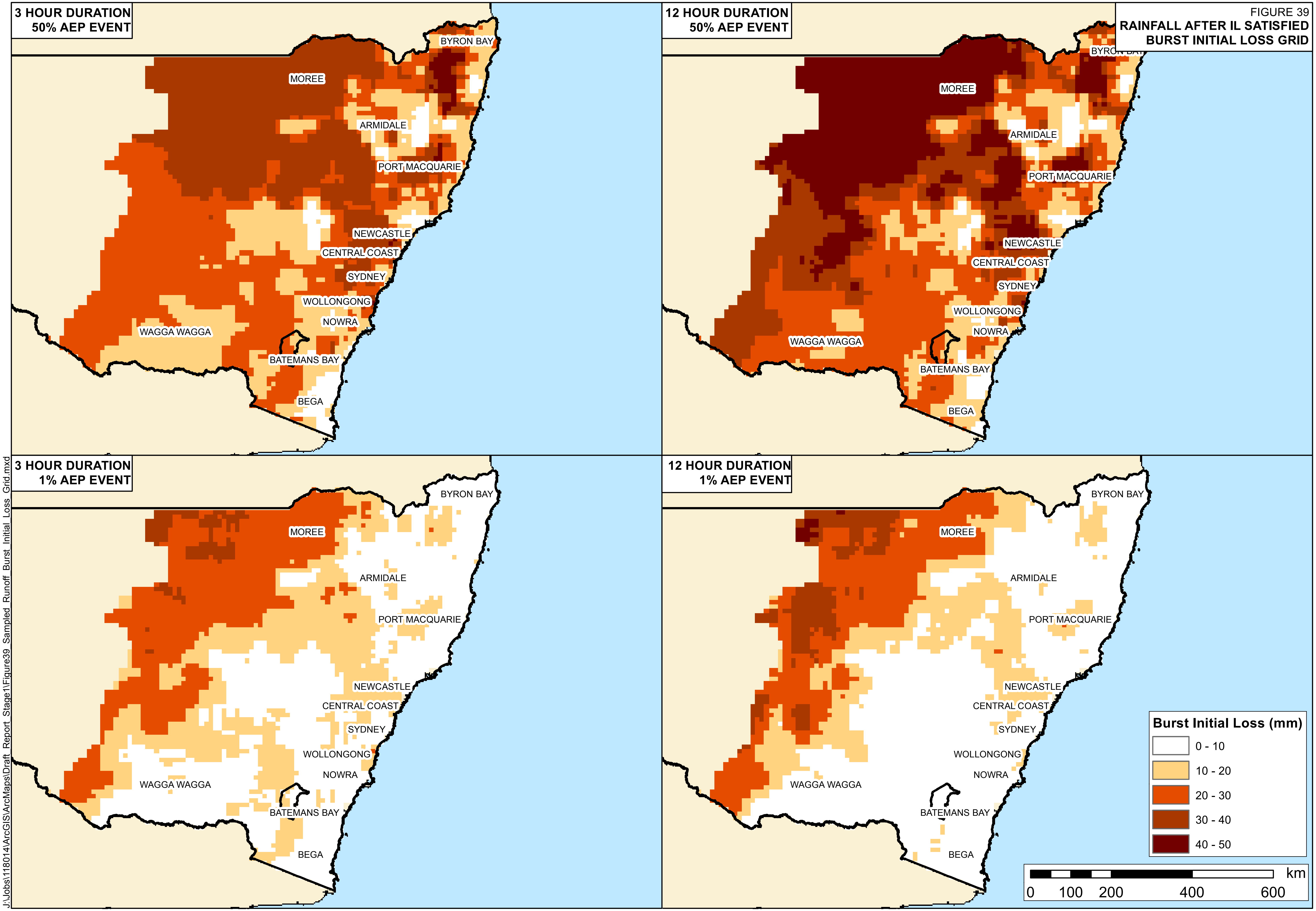

FIGURE 39
RAINFALL AFTER IL SATISFIED
BURST INITIAL LOSS GRID

J:\Jobs\118014\ArcGIS\ArcMaps\Draft_Report_Stage1\Figure39_Sampled_Runoff_Burst_Initial_Loss_Grid.mxd

J:\Jobs\118014\PDF\Report\FIGURE40_Boxplot_Various_Adjustment_Methods.pdf
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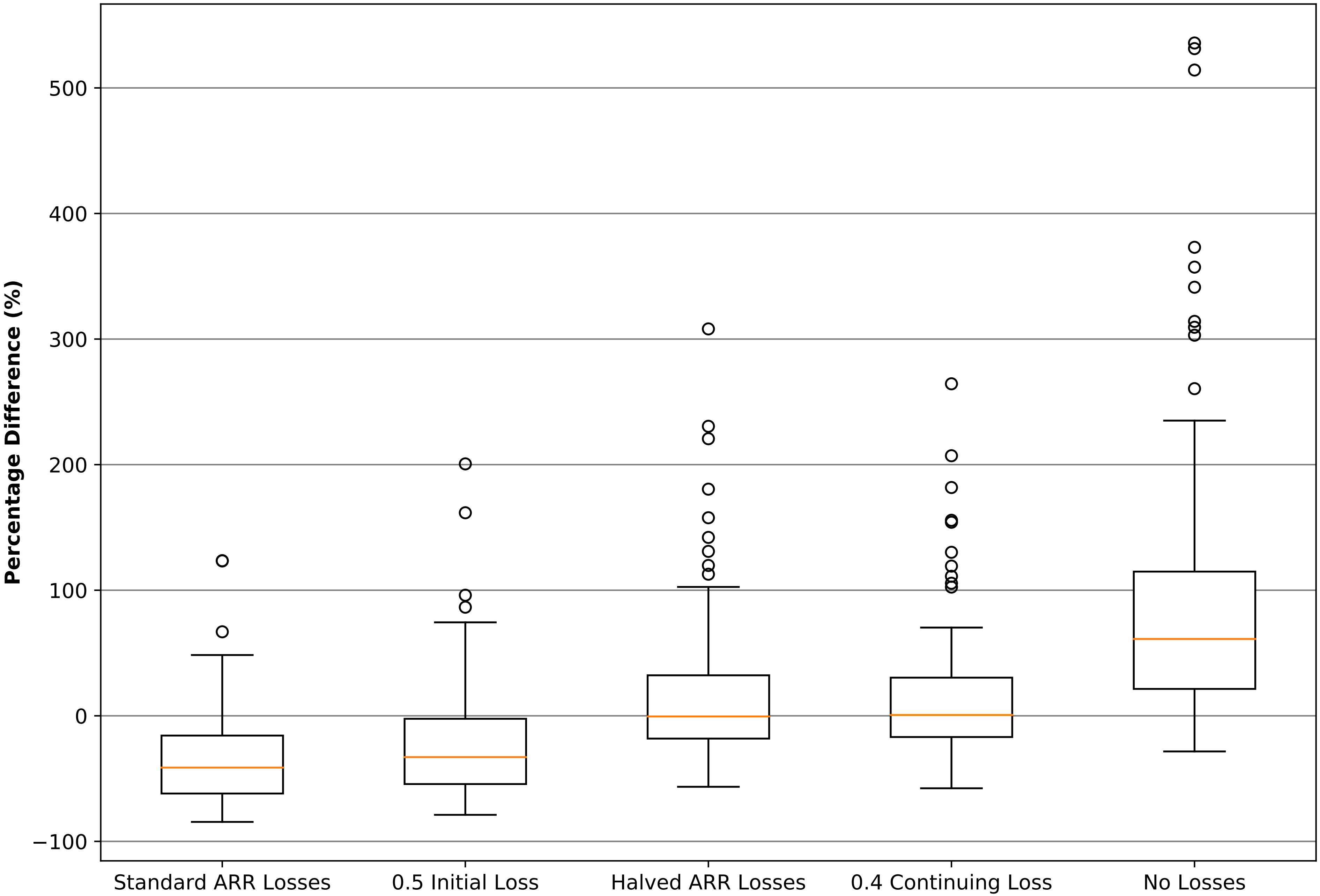

ARR LOSSES ADJUSTMENT FACTORS PERCENTAGE DIFFERENCE ADJUSTED - AT-SITE

FIGURE 40

Appendix A

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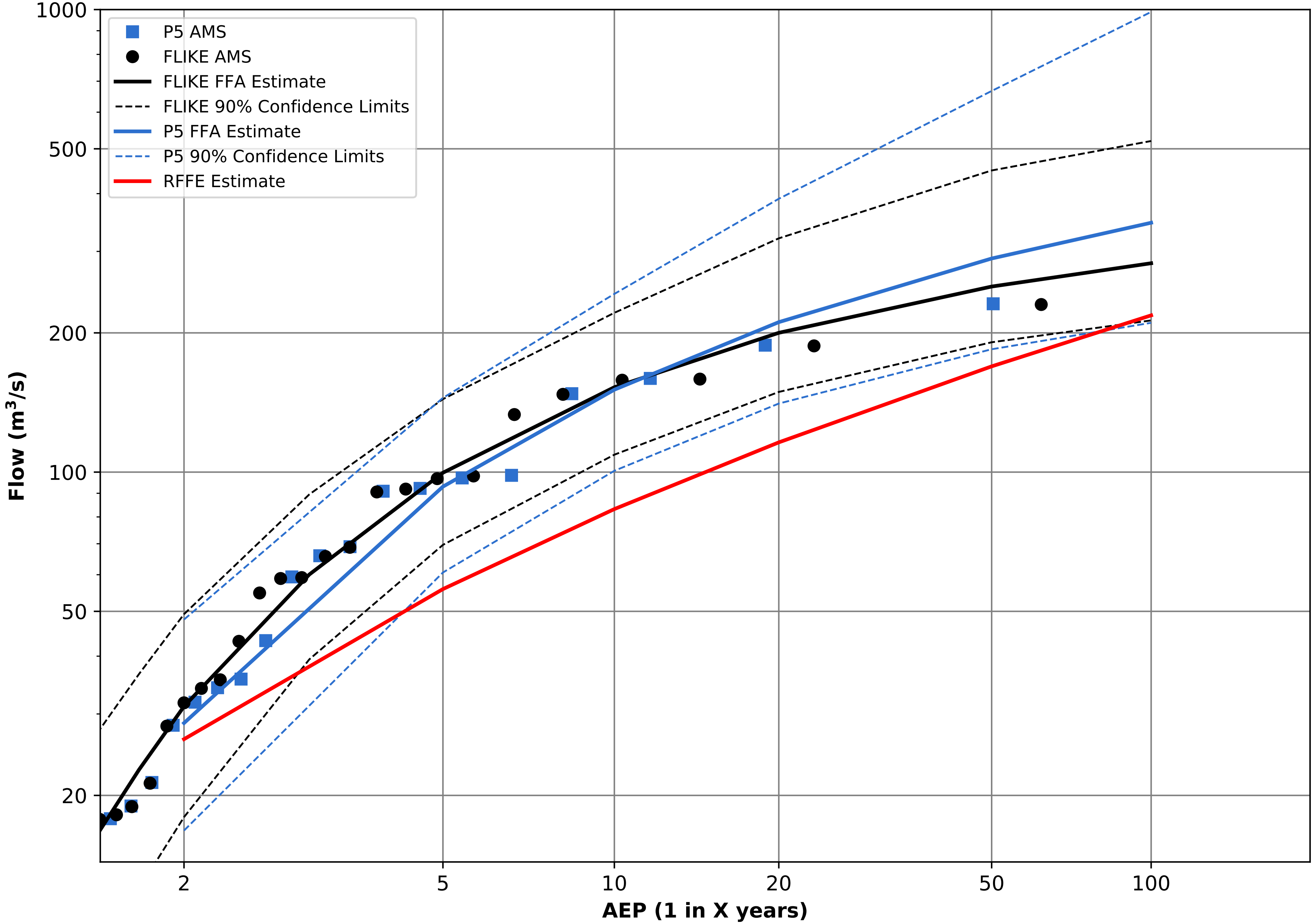
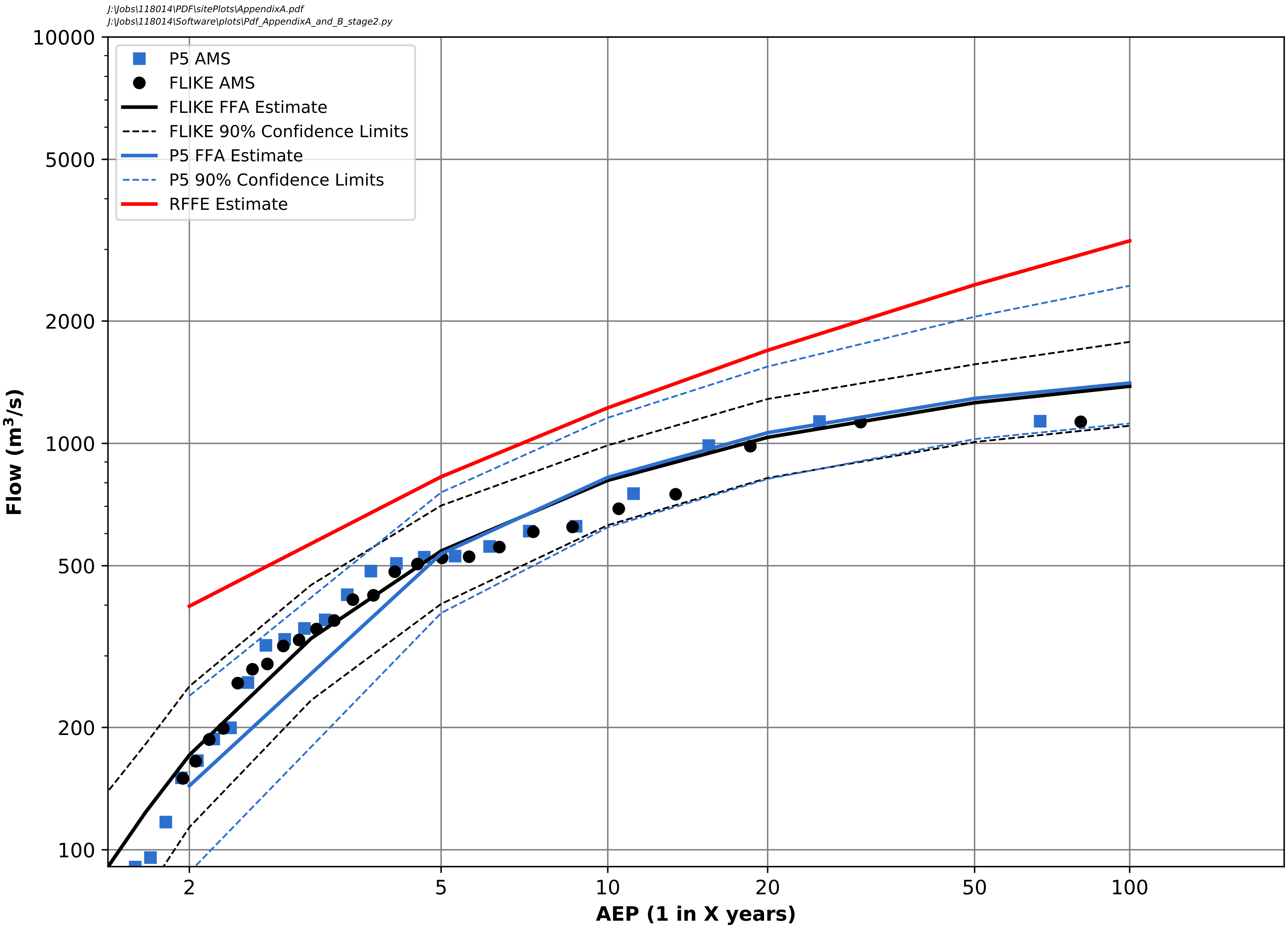
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py



IMLAY RD BR - 221010 [A1]

FFA VARIANTS

APPENDIX A1



PRINCES HWY - 221002 [A2]

FFA VARIANTS

APPENDIX A2

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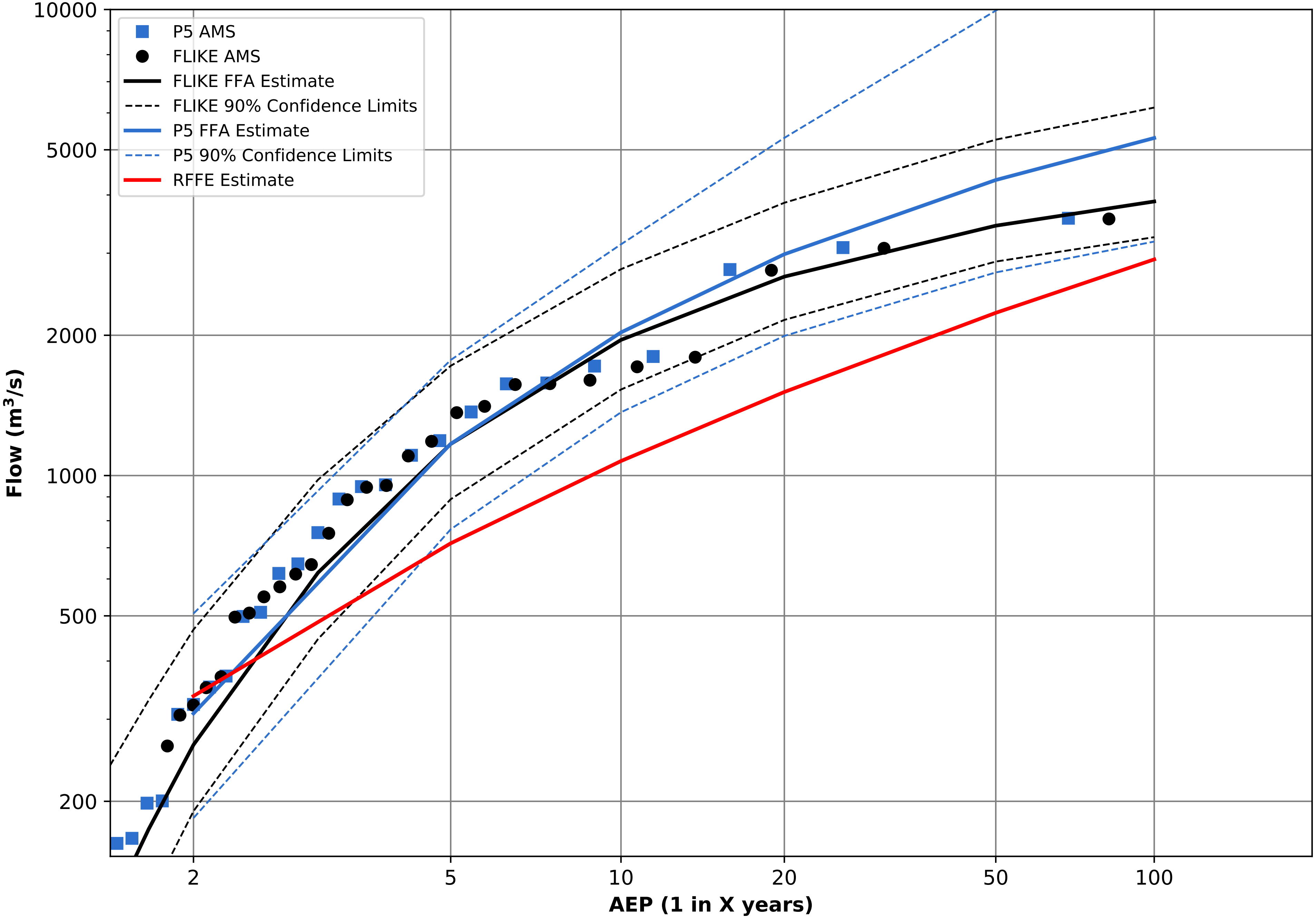

APPENDIX A3

FFA VARIANTS

TOWAMBA - 220004 [A3]

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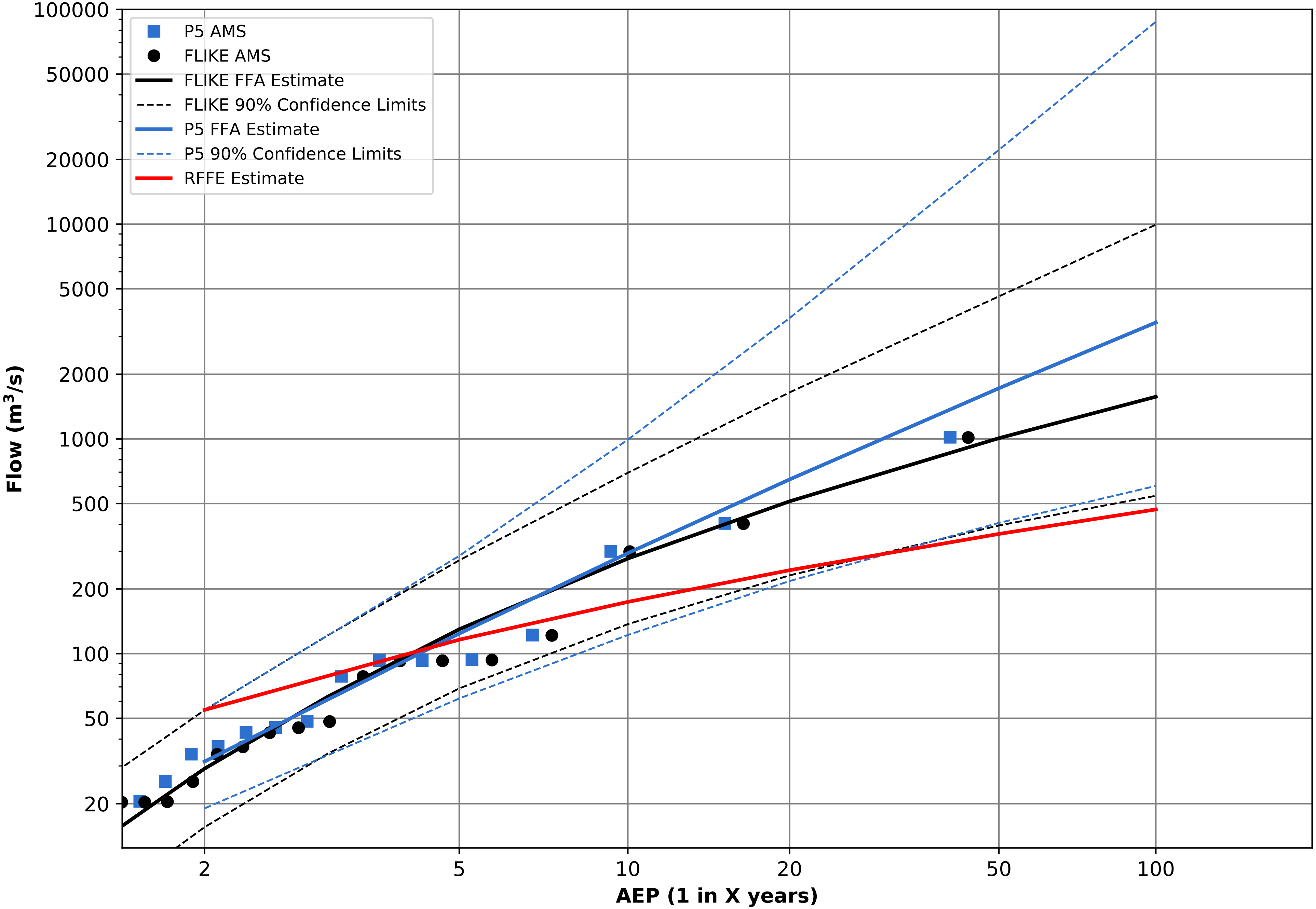

ROCKY HALL (WHITBYS) - 220002 [A4]

FFA VARIANTS

APPENDIX A4

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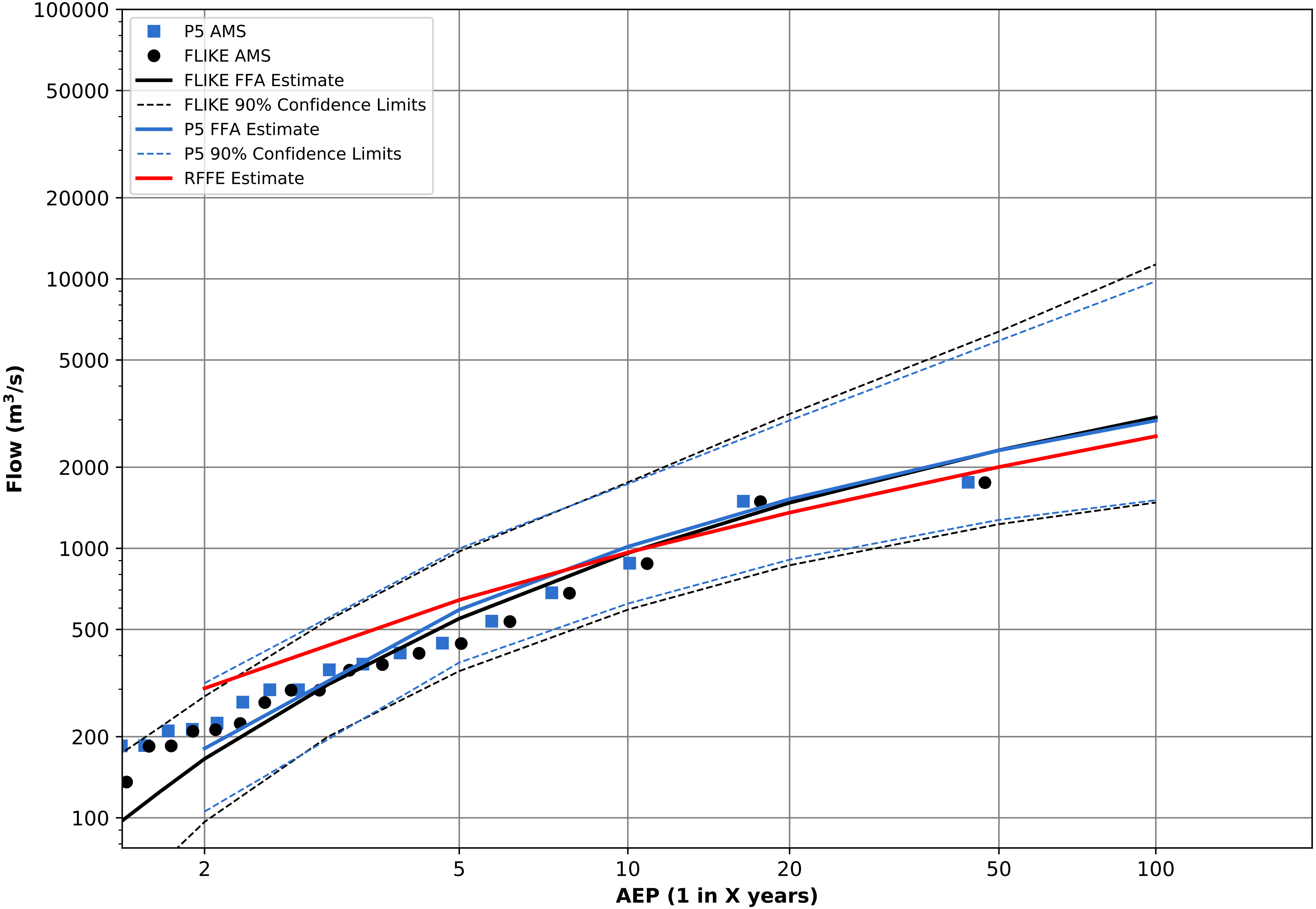

NEW BUILDINGS BR - 220001 [A5]
FFA VARIANTS
APPENDIX A5

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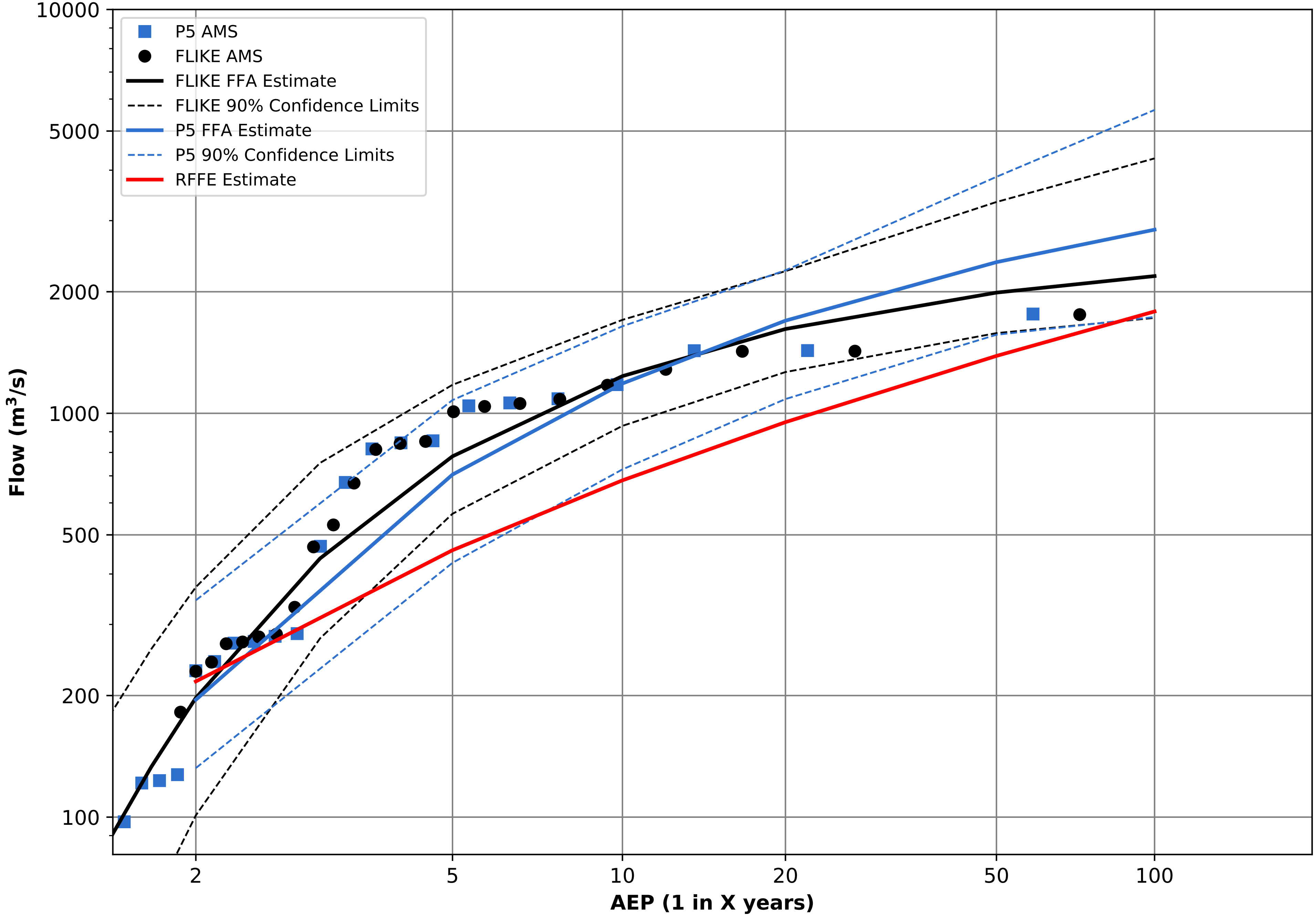
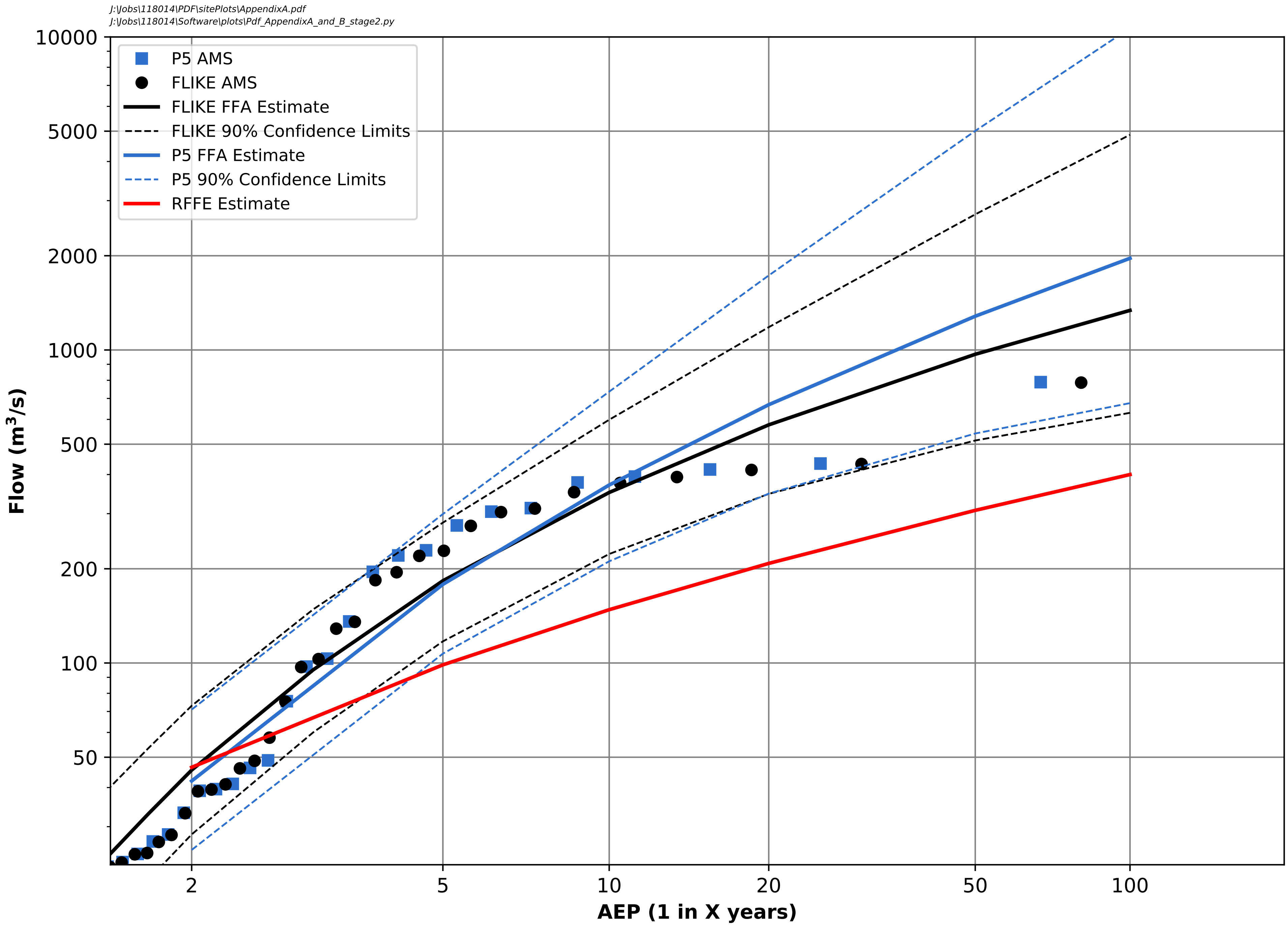


APPENDIX A6

FFA VARIANTS

ANGLEDALE - 219025 [A6]



CANDELO DAM SITE - 219022 [A7]

FFA VARIANTS

APPENDIX A7

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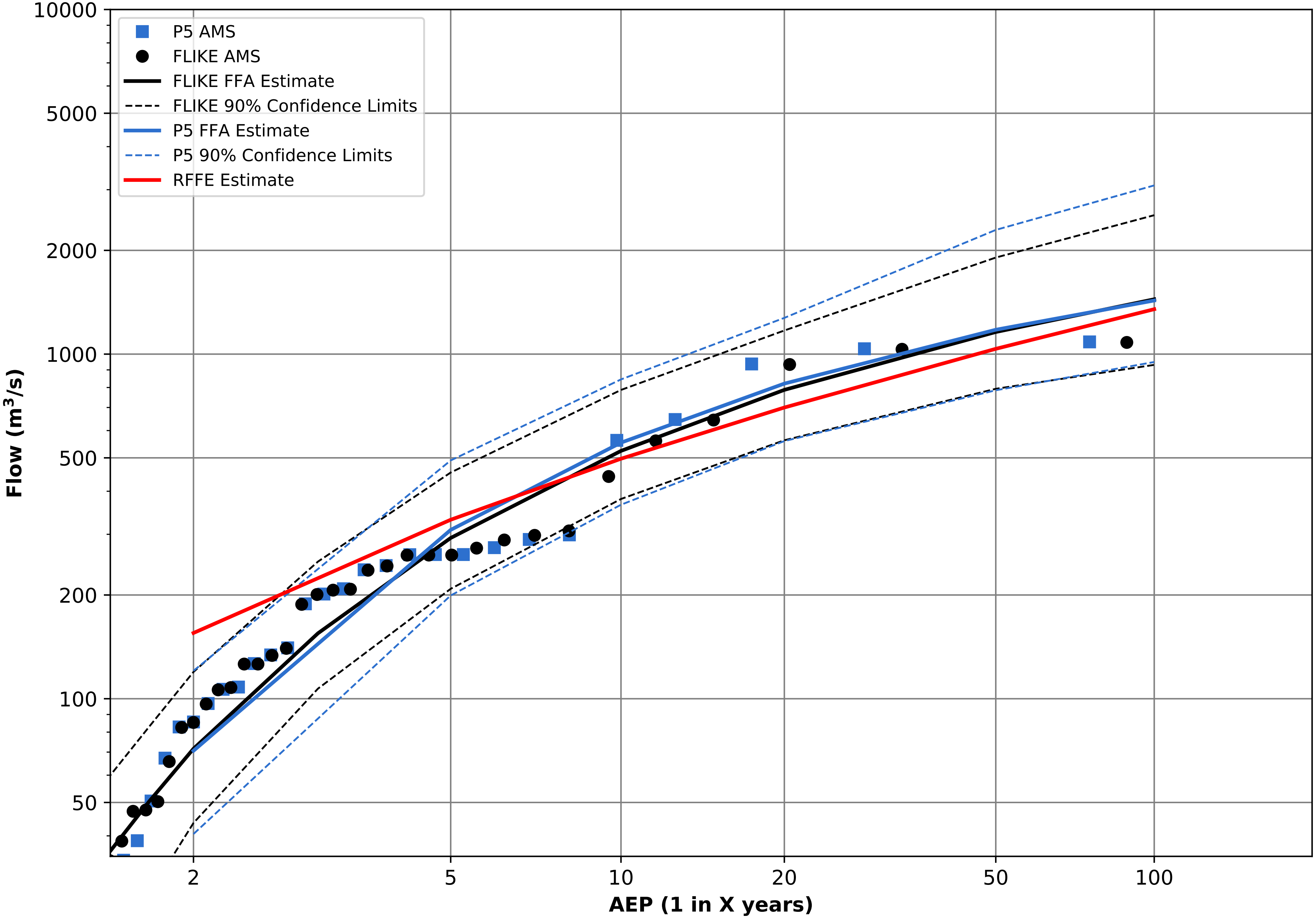

APPENDIX A8
FFA VARIANTS
NEAR BROGO - 219017 [A8]

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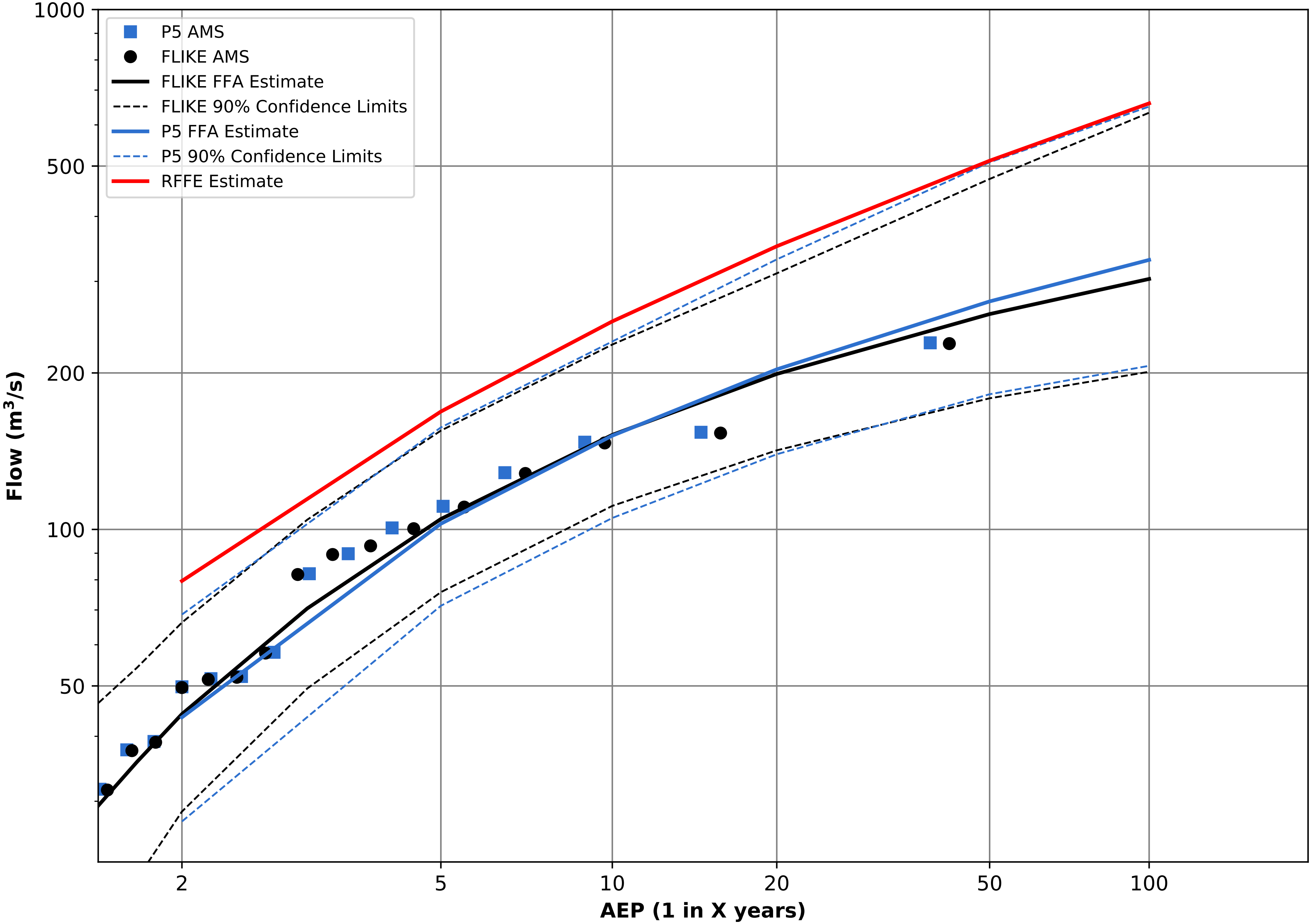
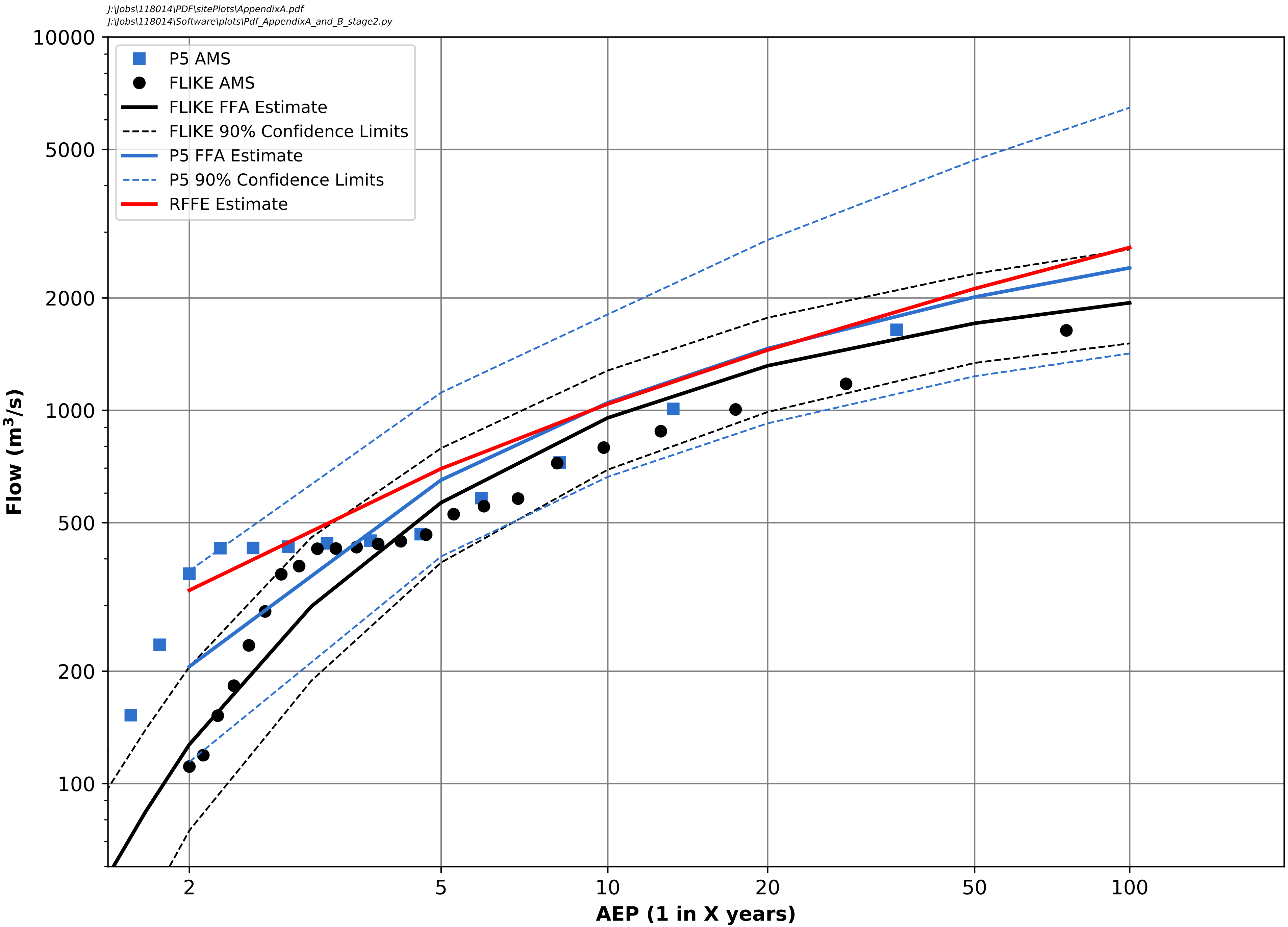


FFA VARIANTS
NEAR BERMAGUI - 219015 [A9]

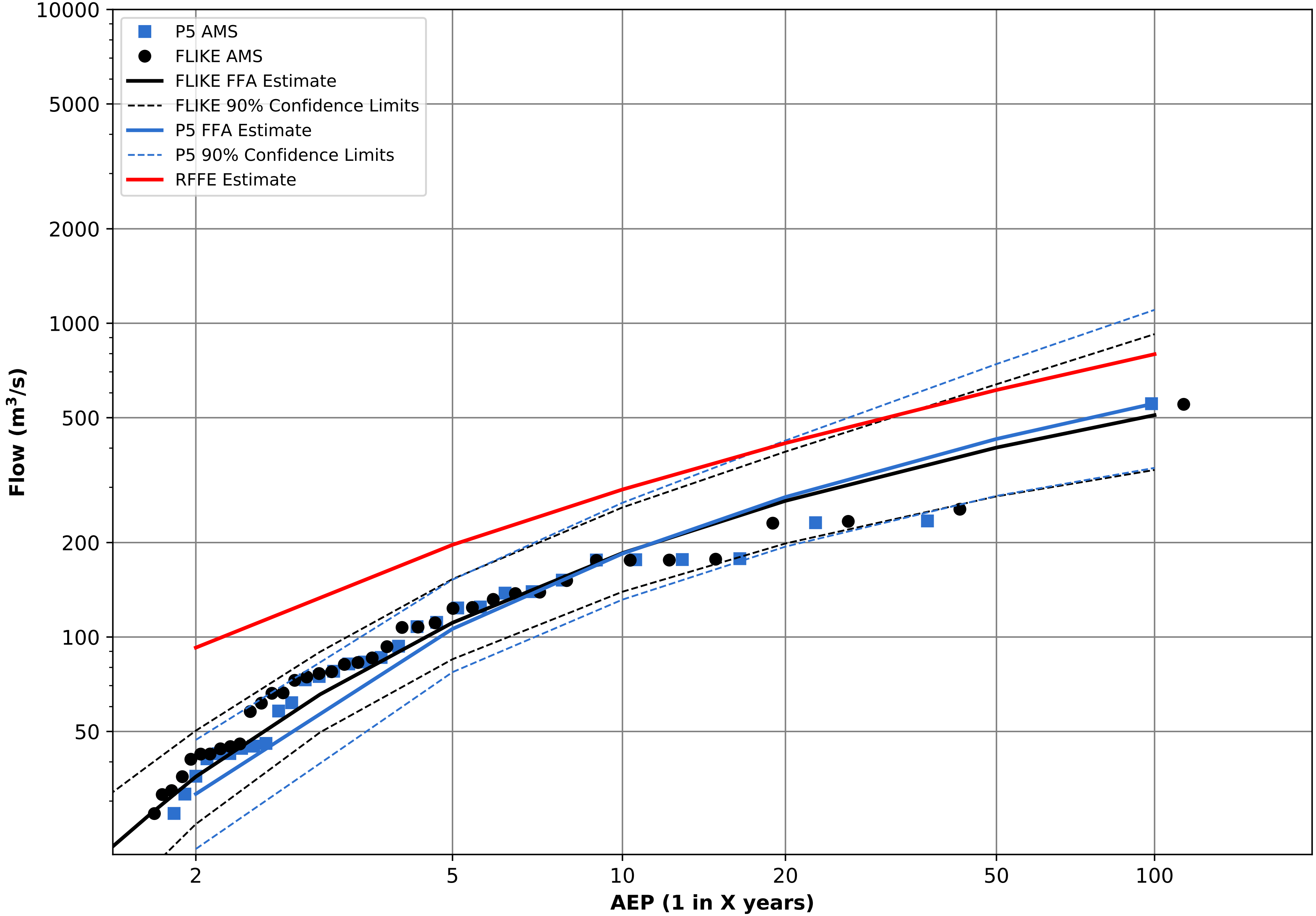
APPENDIX A9



APPENDIX A10

FFA VARIANTS

NORTH BROGO - 219013 [A10]



TANTAWANGALO MOUNTAIN (DAM) - 219006 [A11]
FFA VARIANTS
APPENDIX A11

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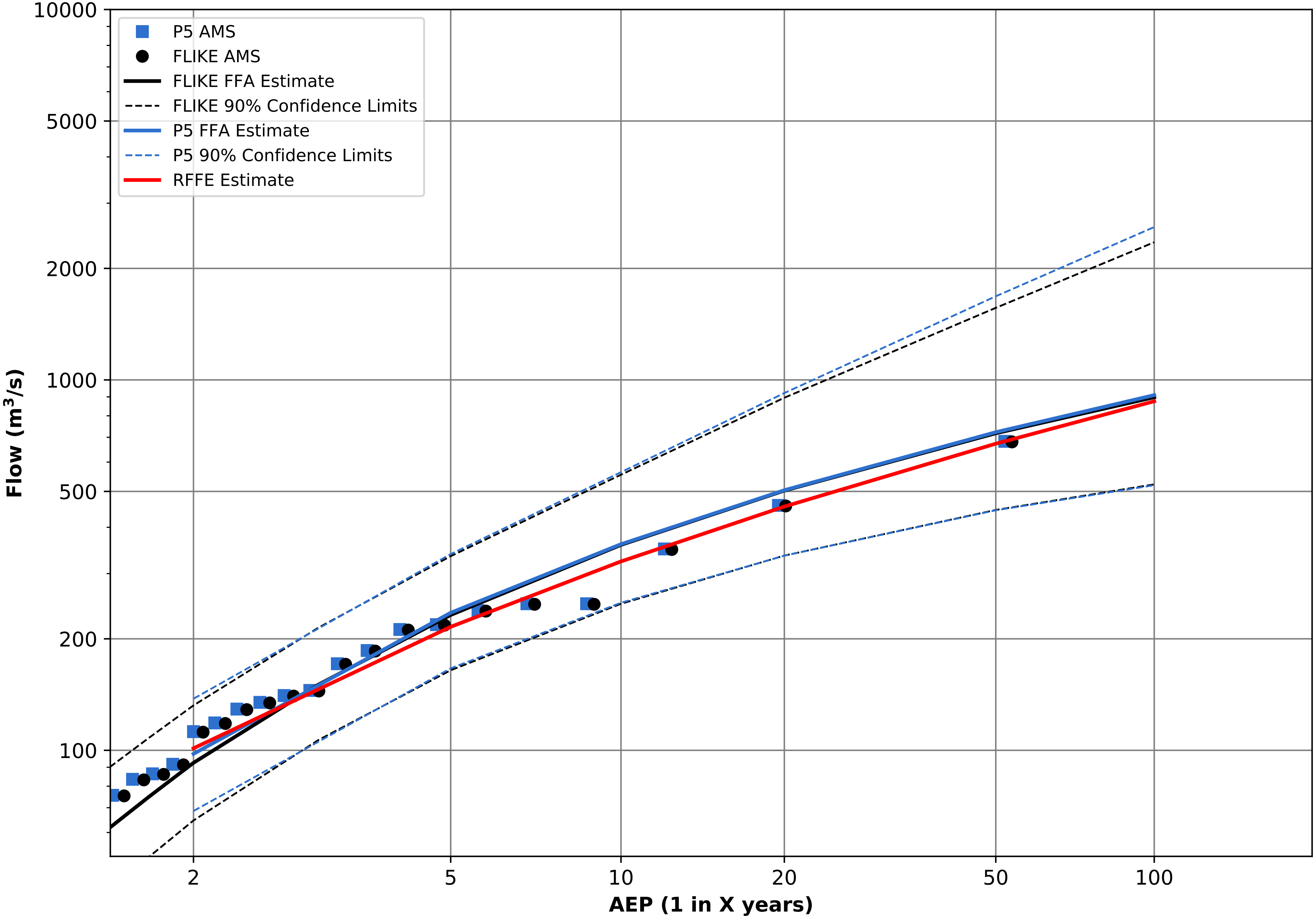
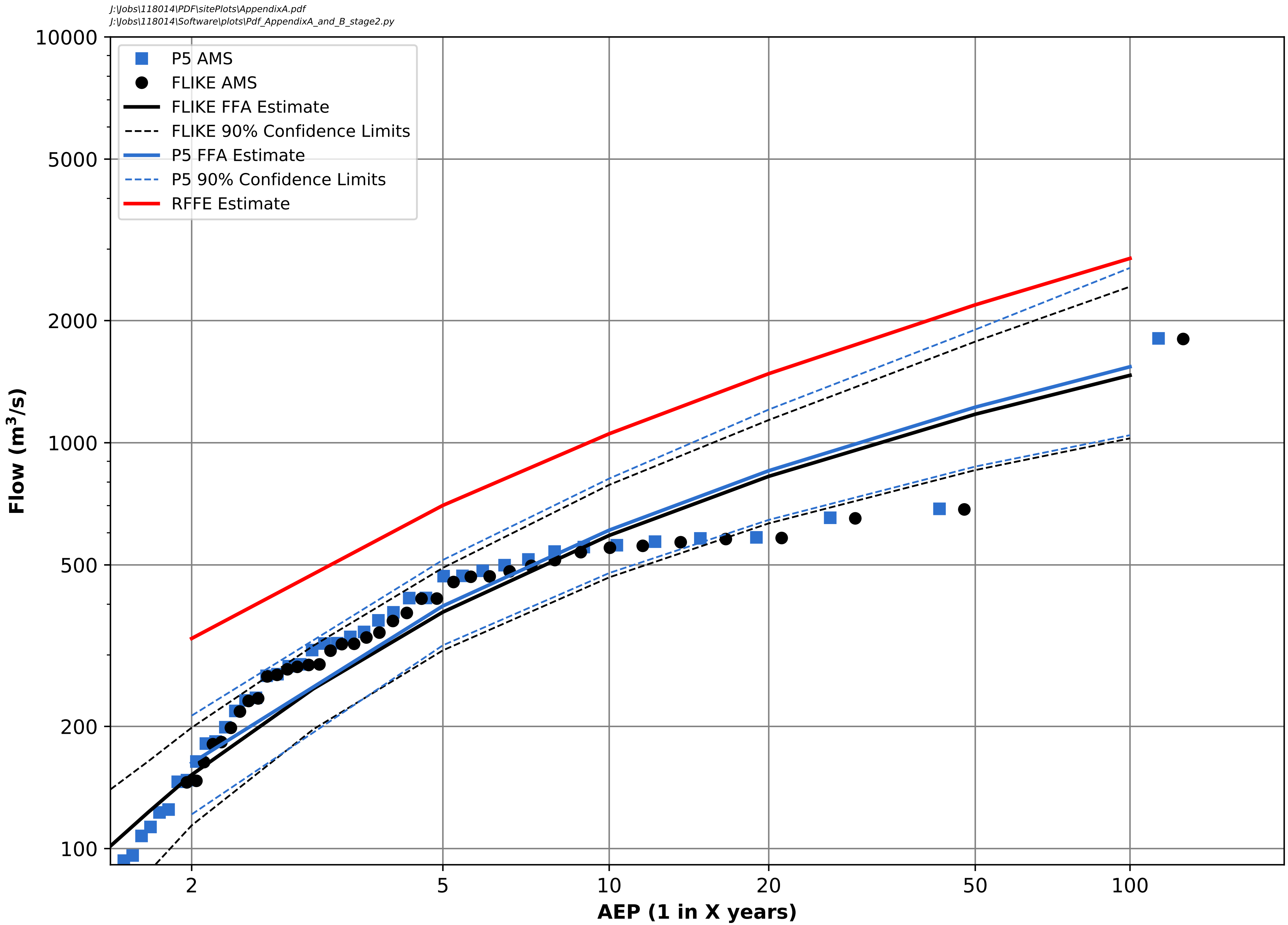


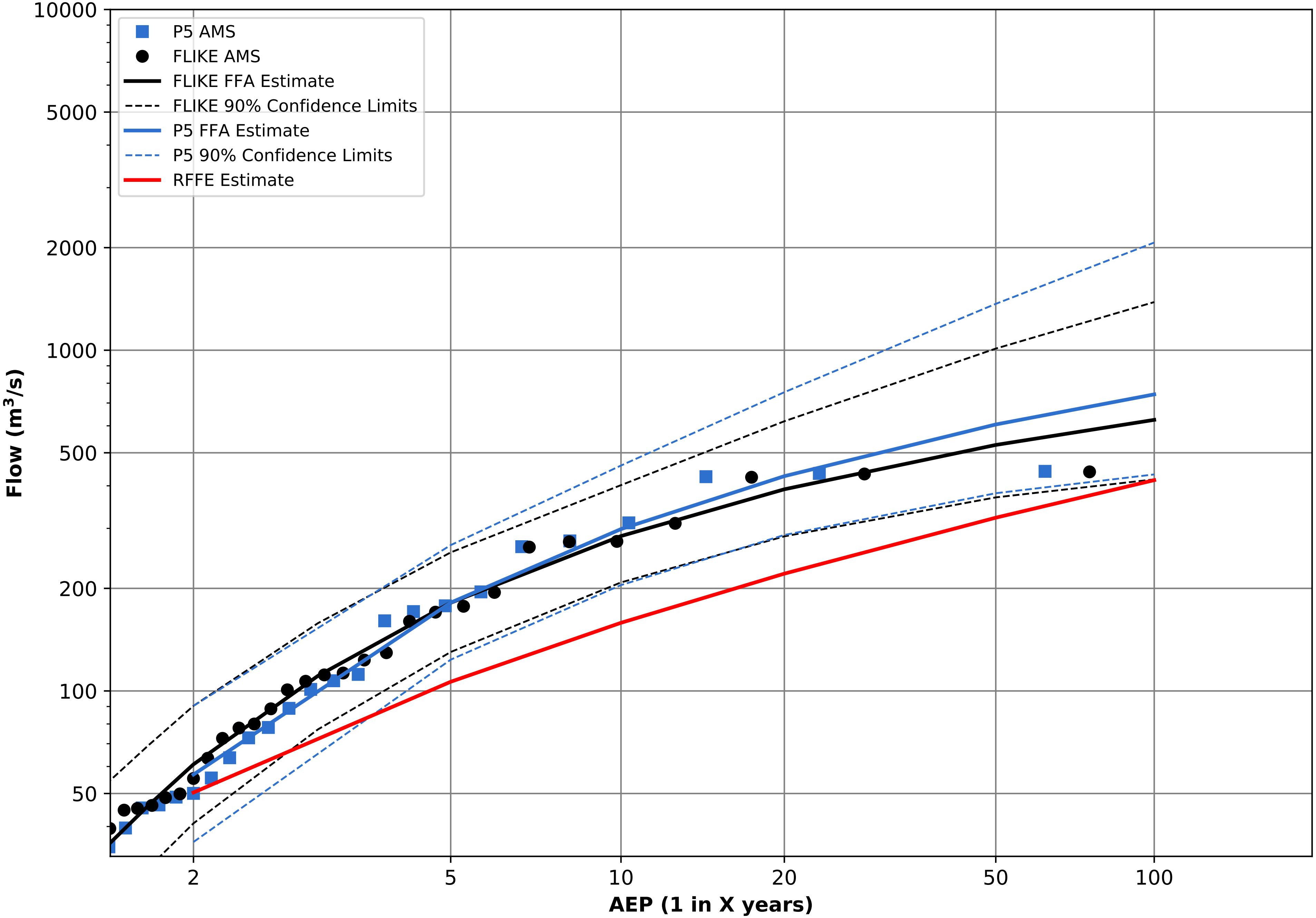
TANTAWANGALO SCHOOL - 219004 [A12]

FFA VARIANTS

APPENDIX A12



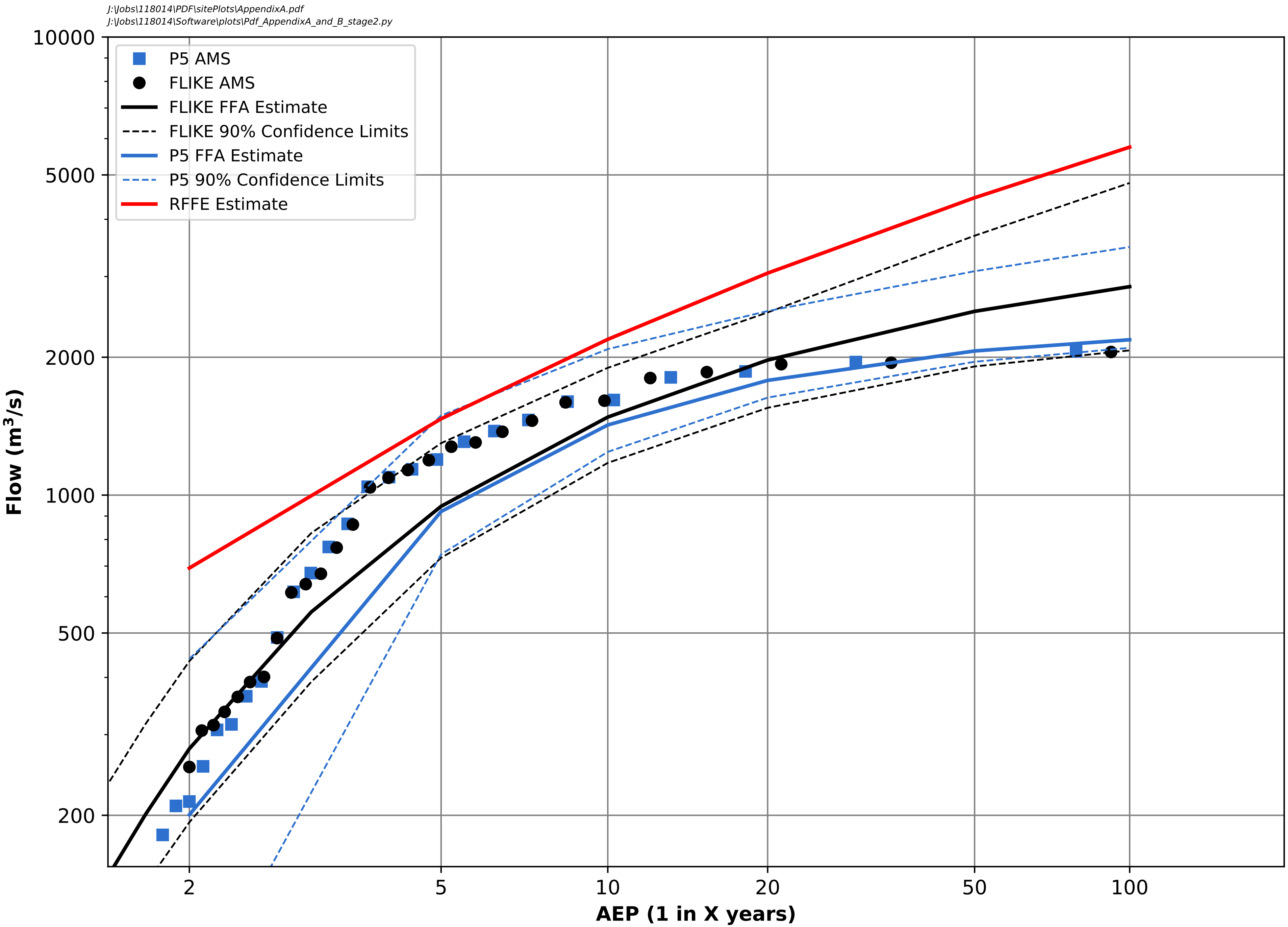
MORANS CROSSING - 219003 [A13]
FFA VARIANTS
APPENDIX A13



WADBILLIGA - 218007 [A14]

FFA VARIANTS

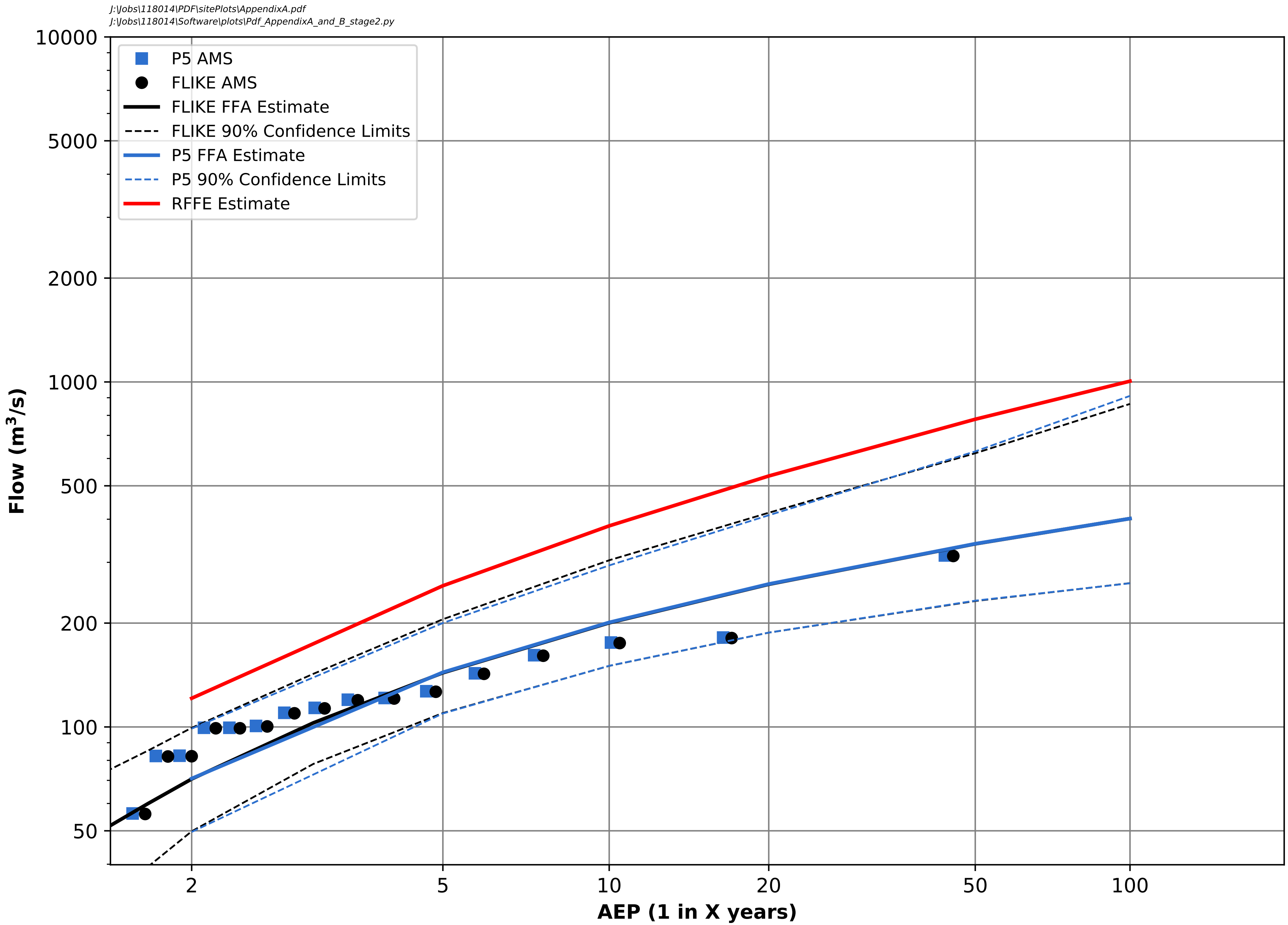
APPENDIX A14



D/S WADBILLIGA R JUNCT - 218005 [A15]

FFA VARIANTS

APPENDIX A15



YOWRIE - 218003 [A16]
FFA VARIANTS
APPENDIX A16

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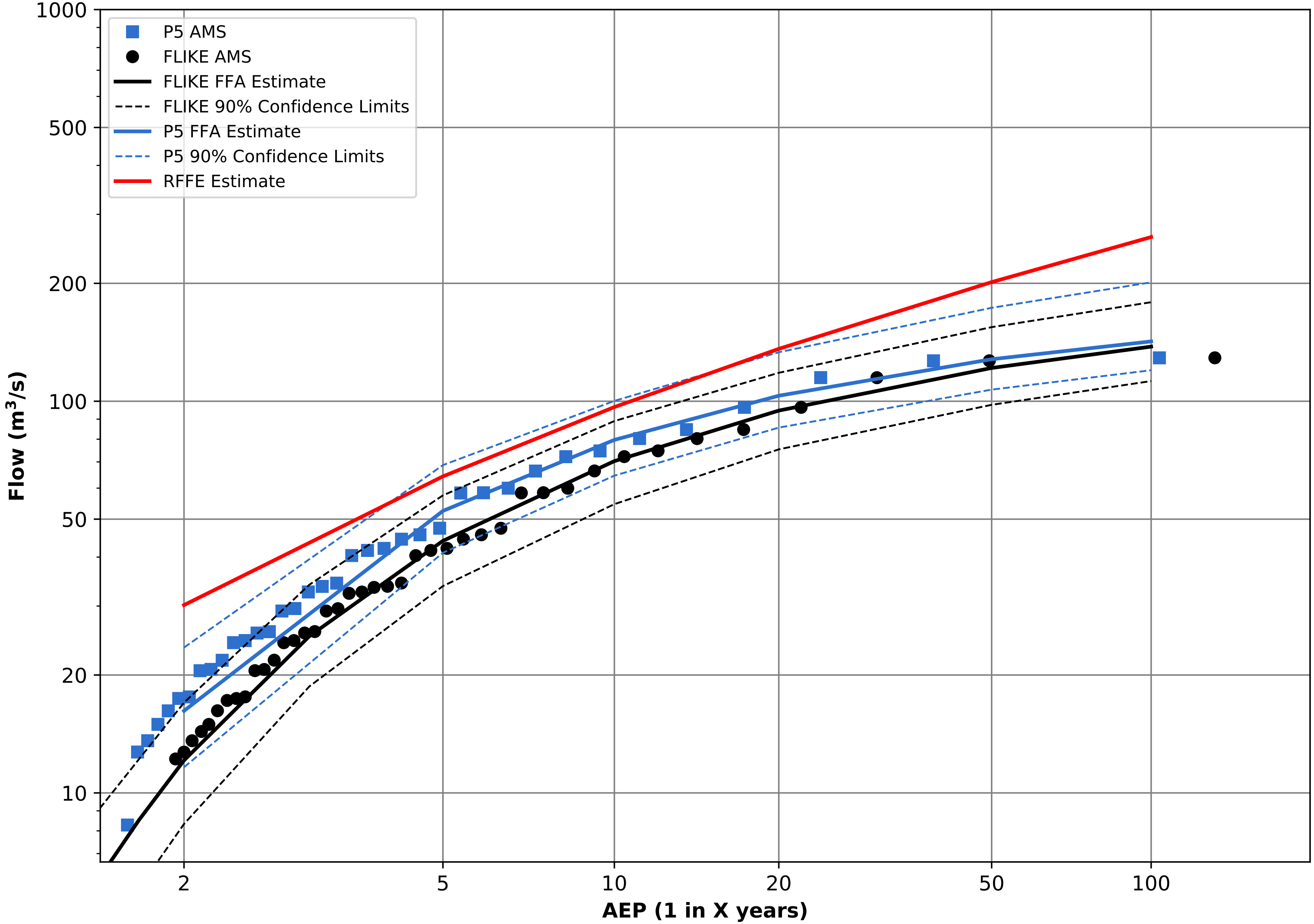

BROWN MOUNTAIN - 219001 [A17]
FFA VARIANTS

APPENDIX A17

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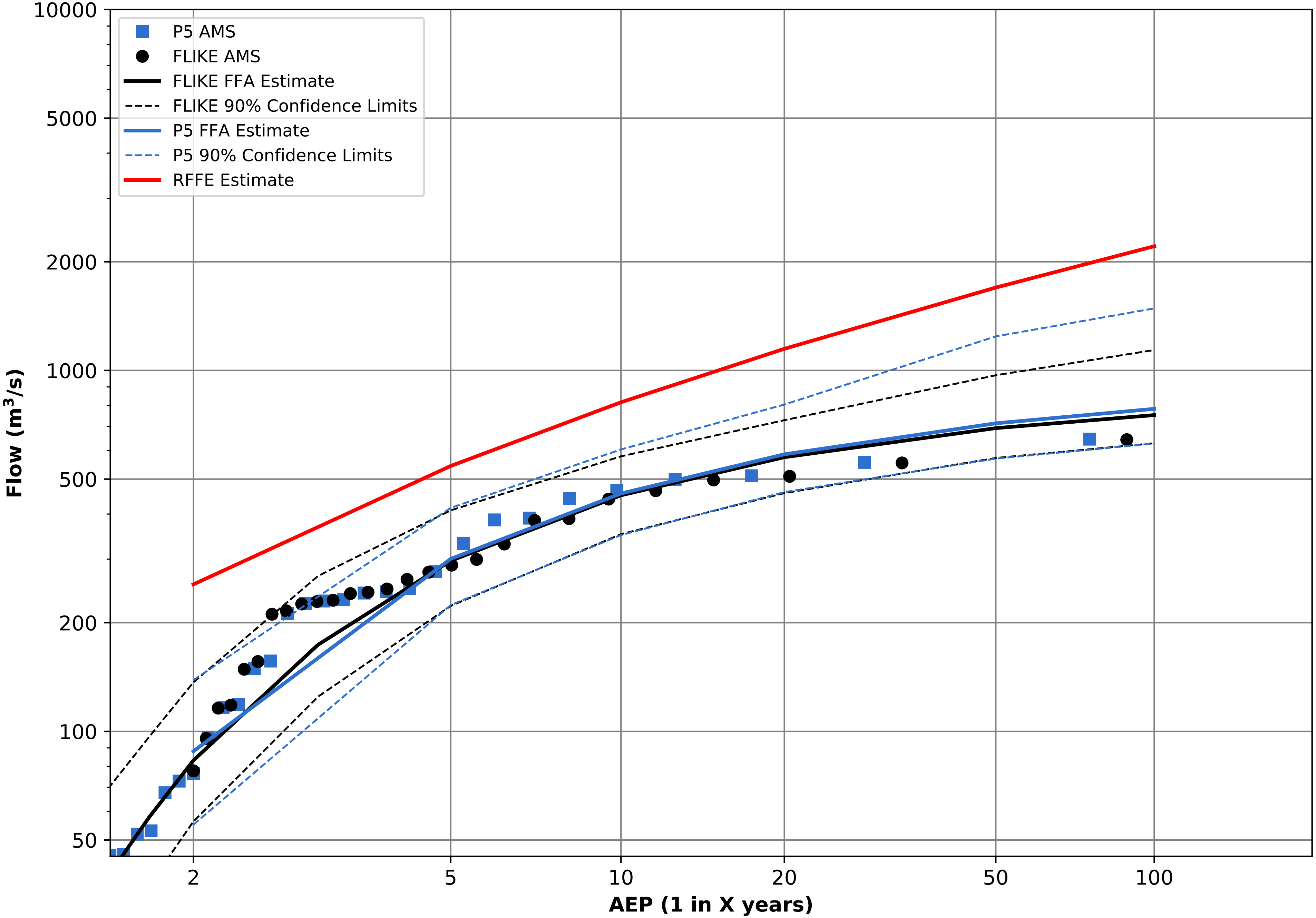

APPENDIX A18

FFA VARIANTS

LOCHIEL - 220003 [A18]

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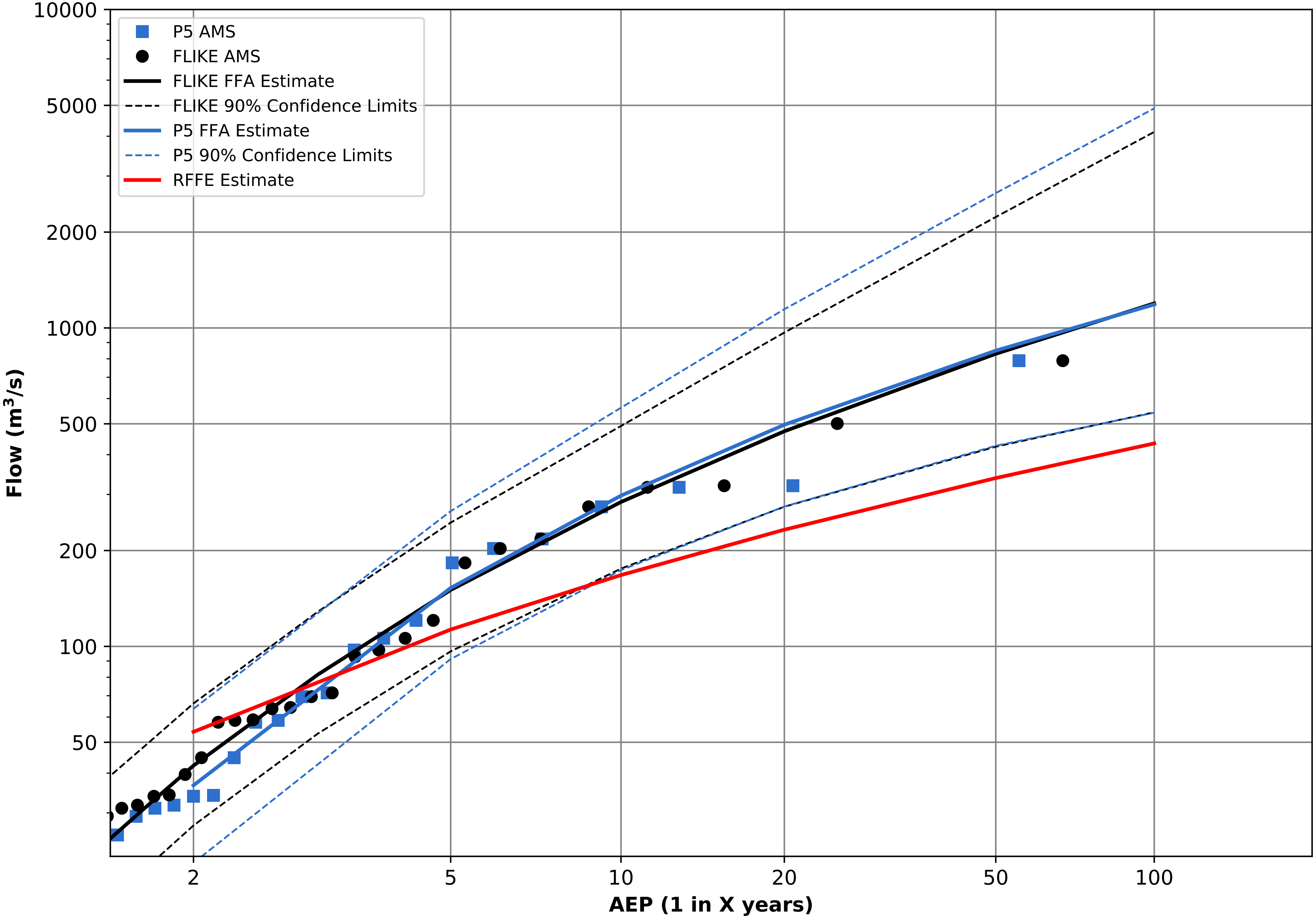

THE HUT - 222017 [B1]
FFA VARIANTS
APPENDIX A19

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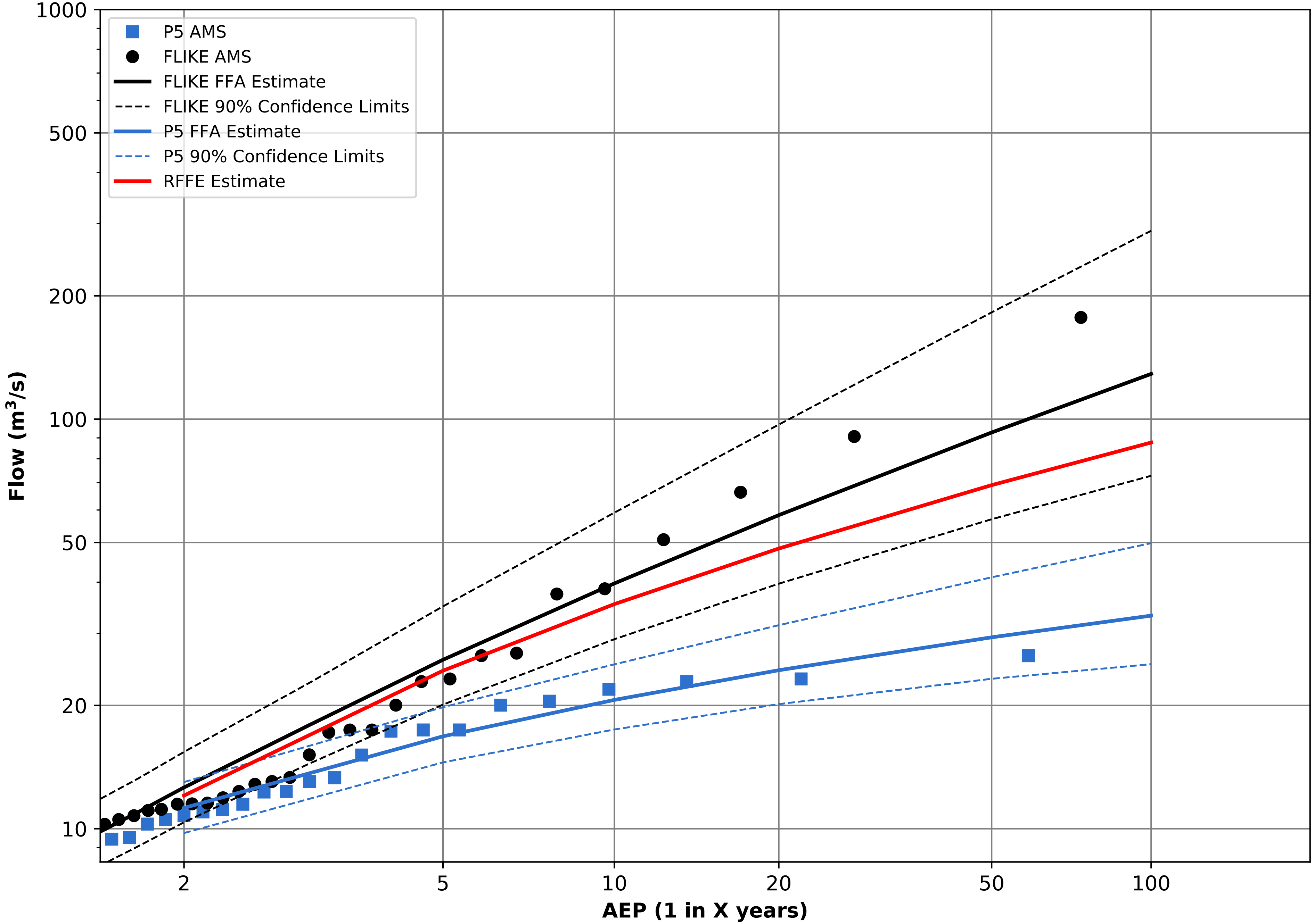

THE BARRY WAY - 222016 [B2]
FFA VARIANTS
APPENDIX A20

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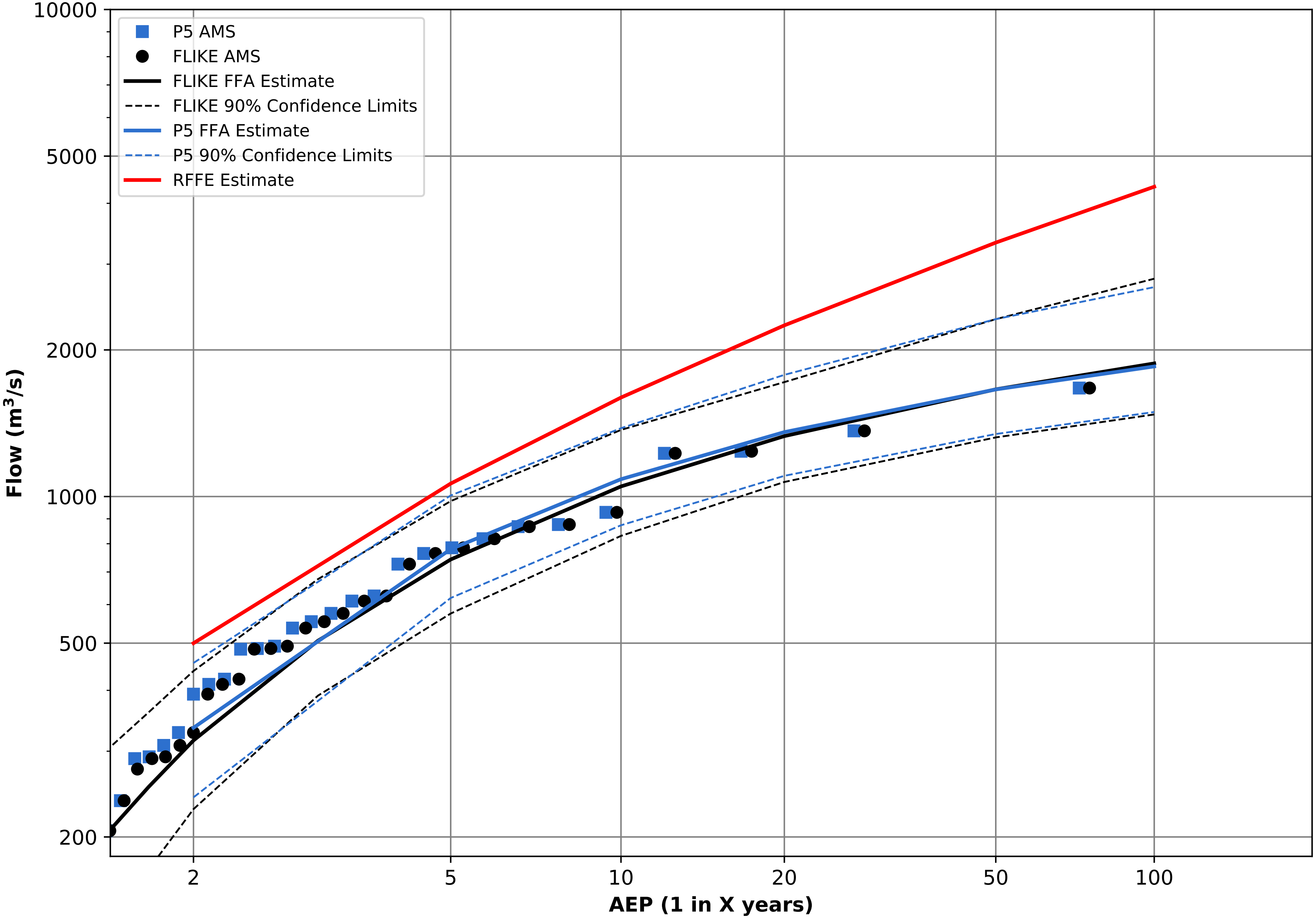
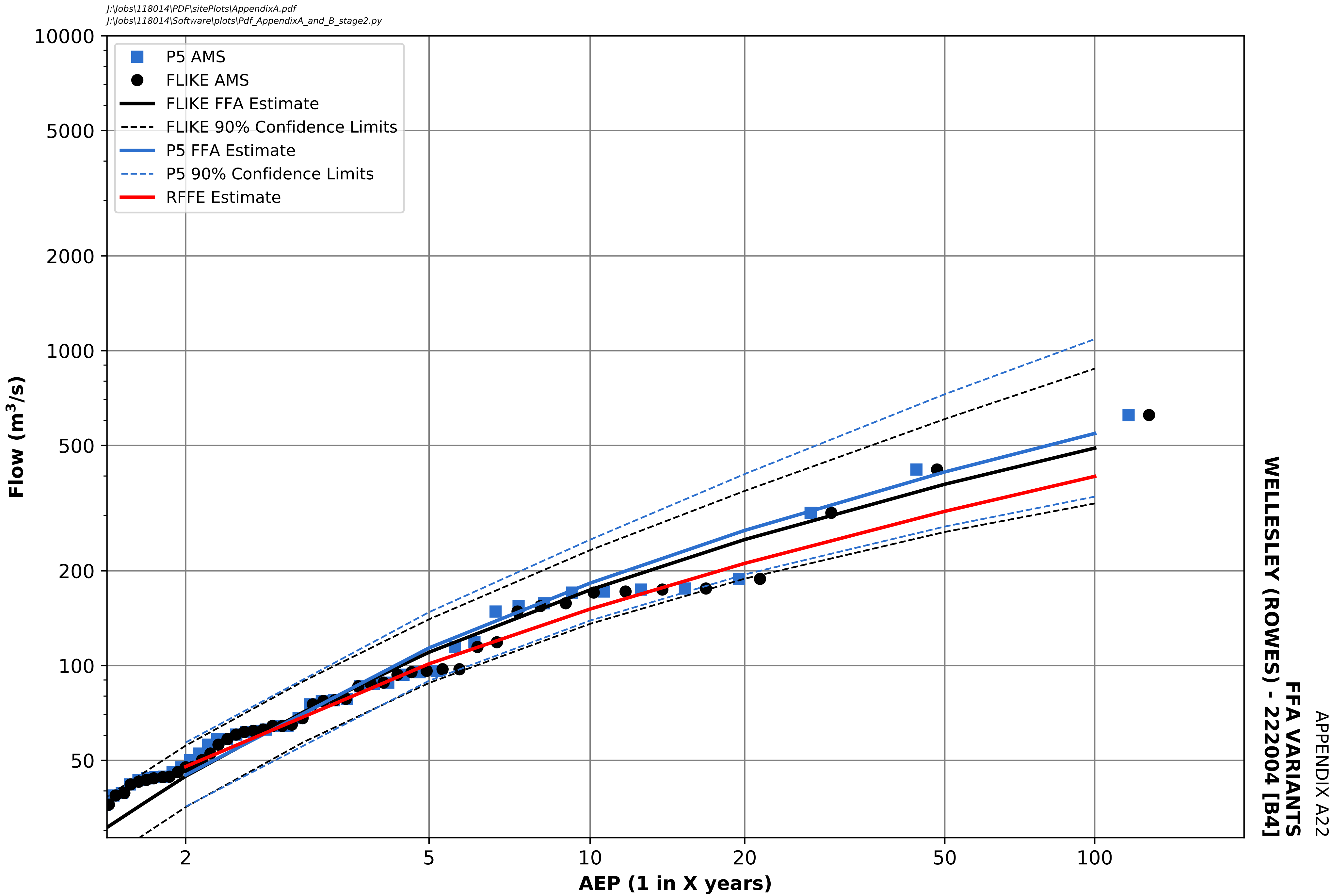


THE FALLS - 222009 [B3]
FFA VARIANTS
APPENDIX A21



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P5 AMS
FLIKE AMS
FLIKE FFA Estimate
FLIKE 90% Confidence Limits
P5 FFA Estimate
P5 90% Confidence Limits
RFFE Estimate
Flow (m³/s)
10000
5000
2000
1000
500
200
100
50
2
5
10
20
50
100
AEP (1 in X years)
WELLESLEY (ROWES) - 222004 [B4]
FFA VARIANTS
APPENDIX A22

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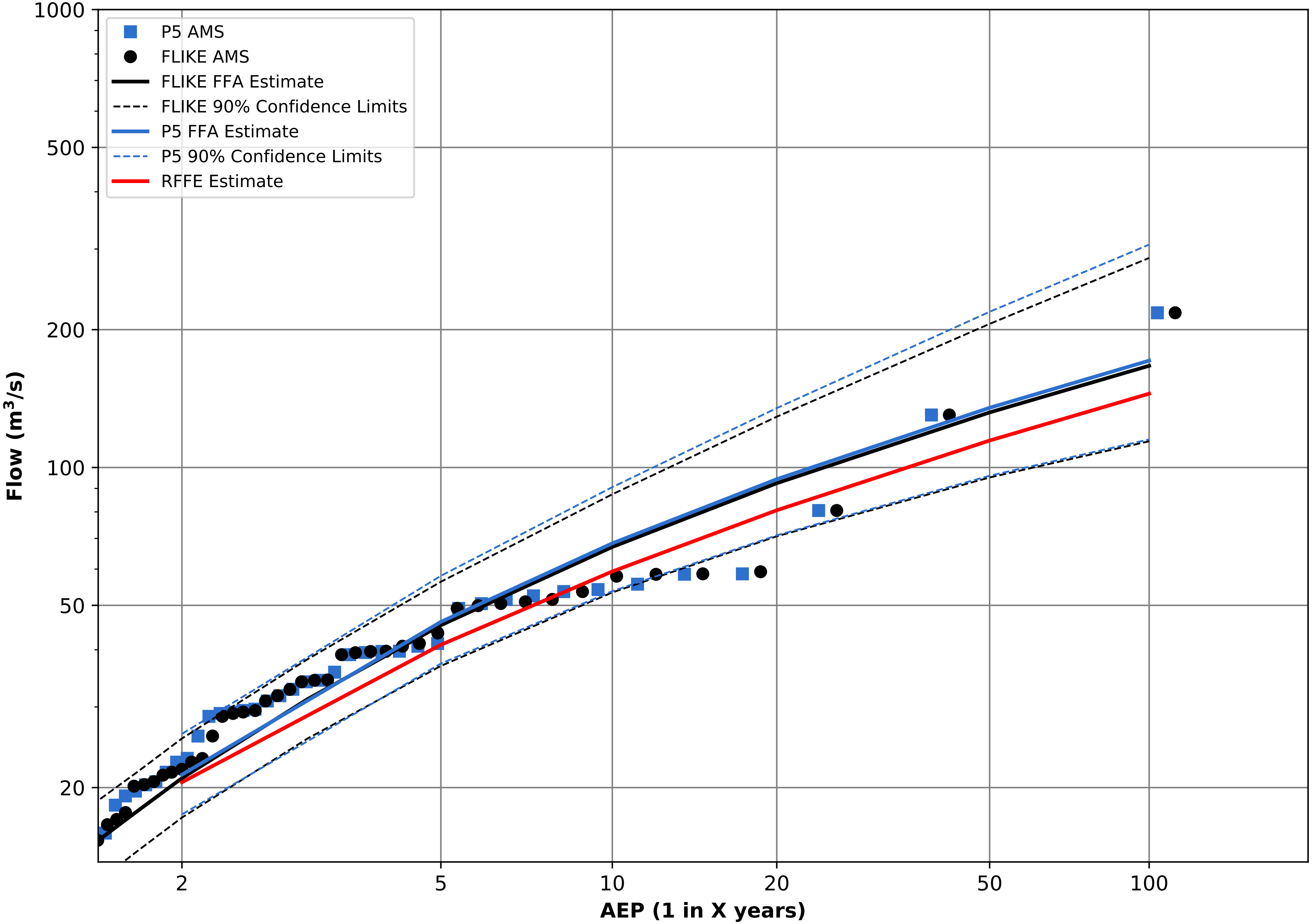

MARAGLE - 401009 [C2]
FFA VARIANTS
APPENDIX A23

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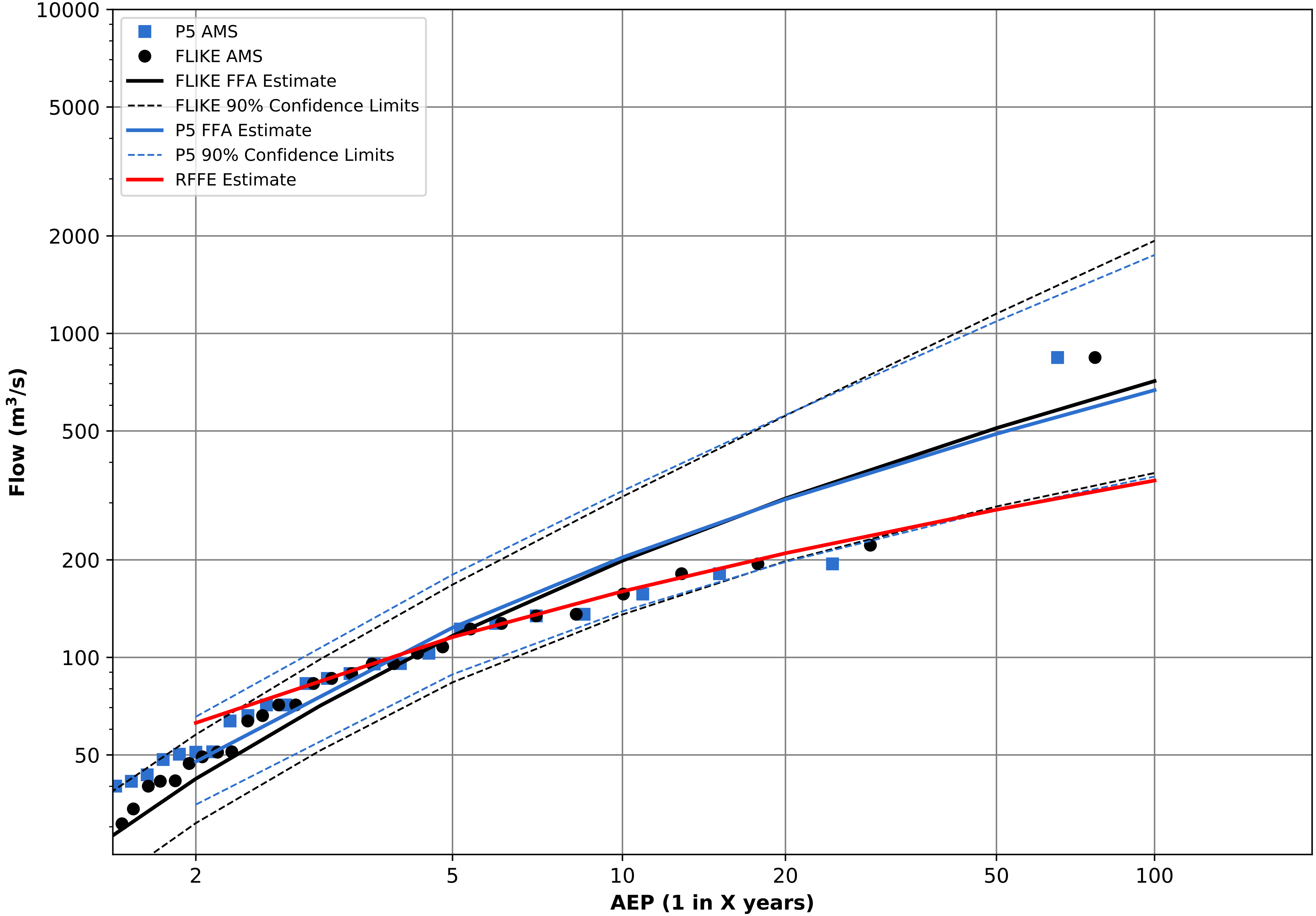
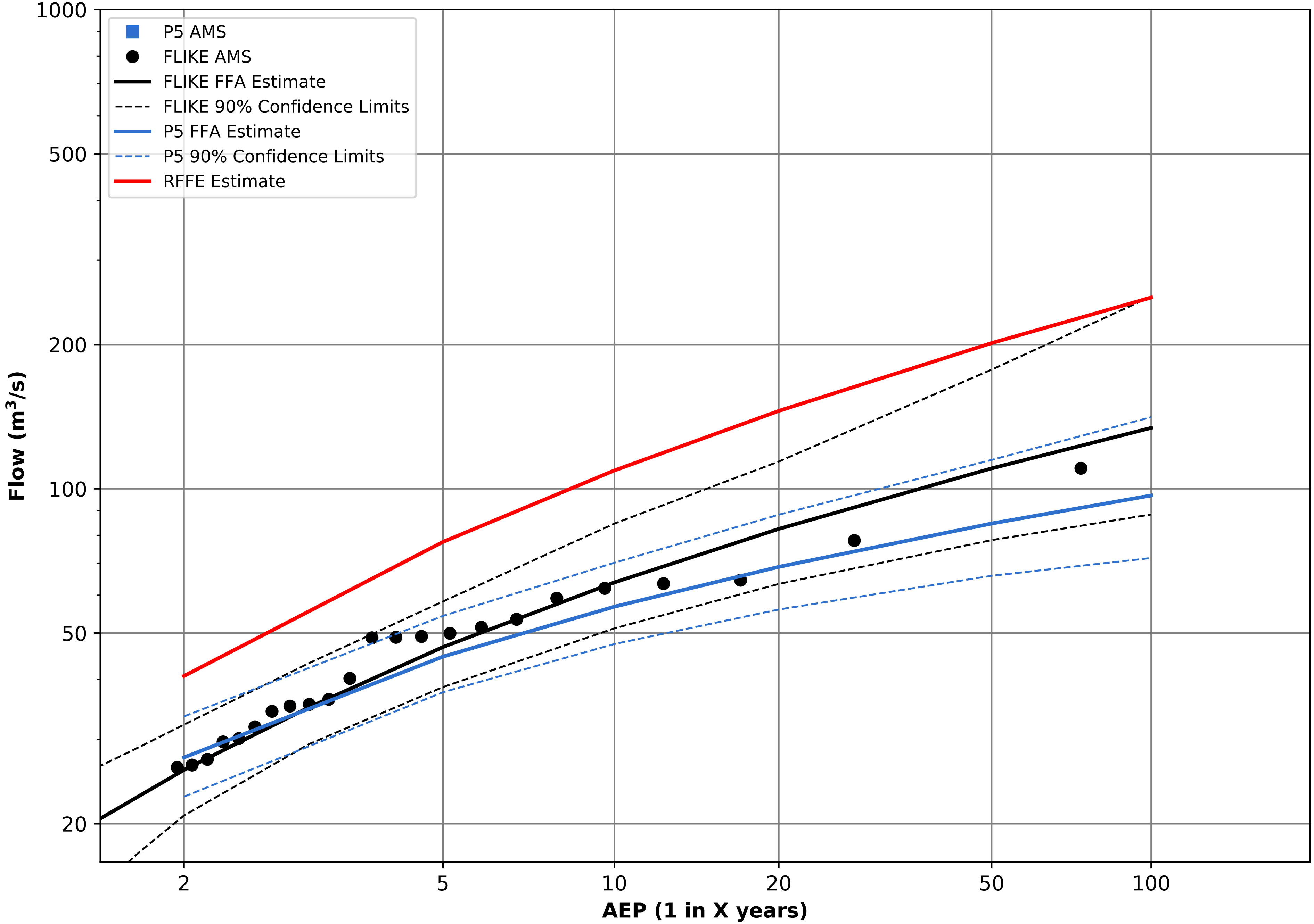


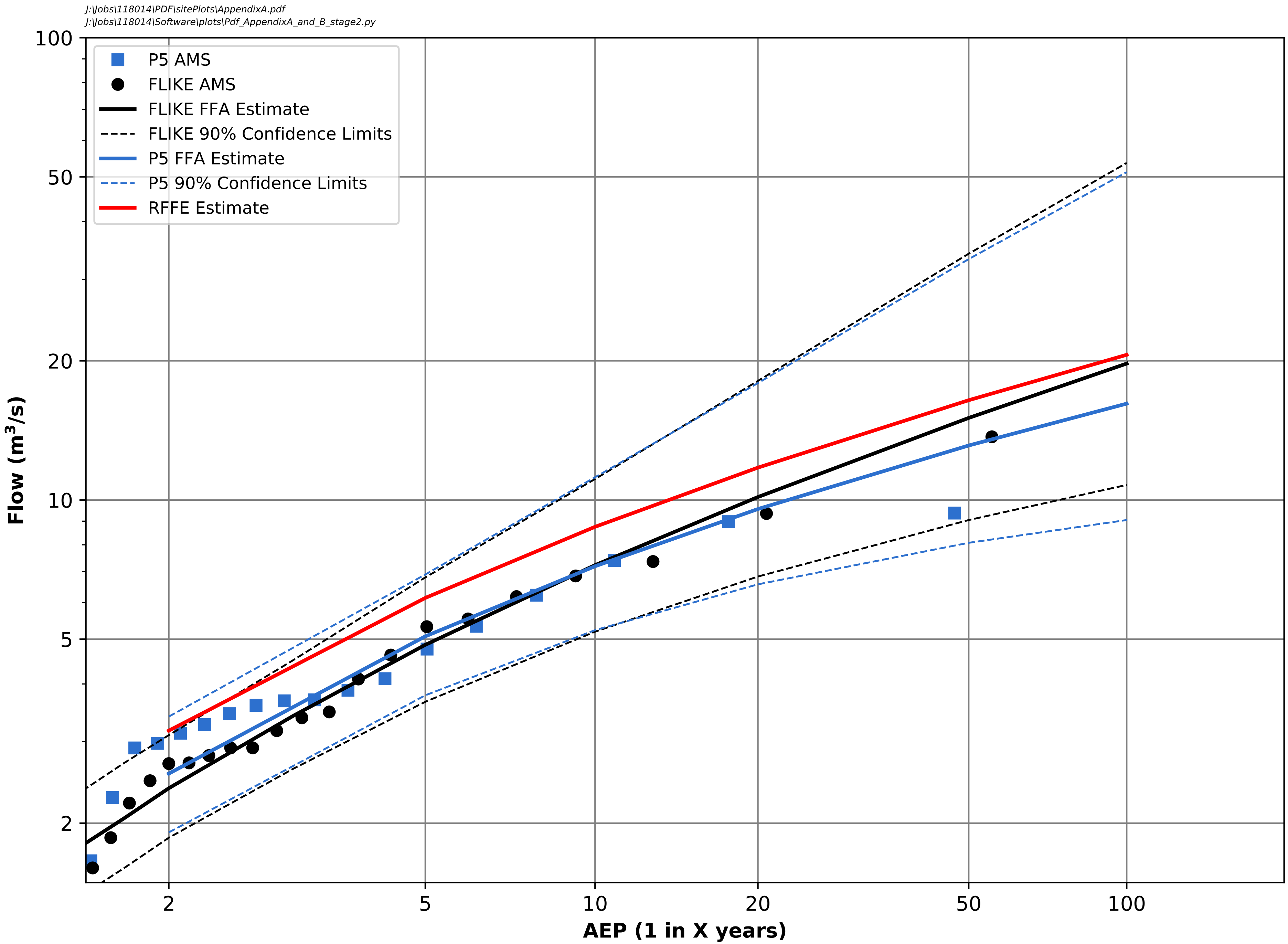
JINGELLIC - 401013 [C3]

FFA VARIANTS

APPENDIX A24



YAMBLA - 401015 [C4]
FFA VARIANTS
APPENDIX A25



APPENDIX A26
FFA VARIANTS
THE SQUARE - 401016 [C5]

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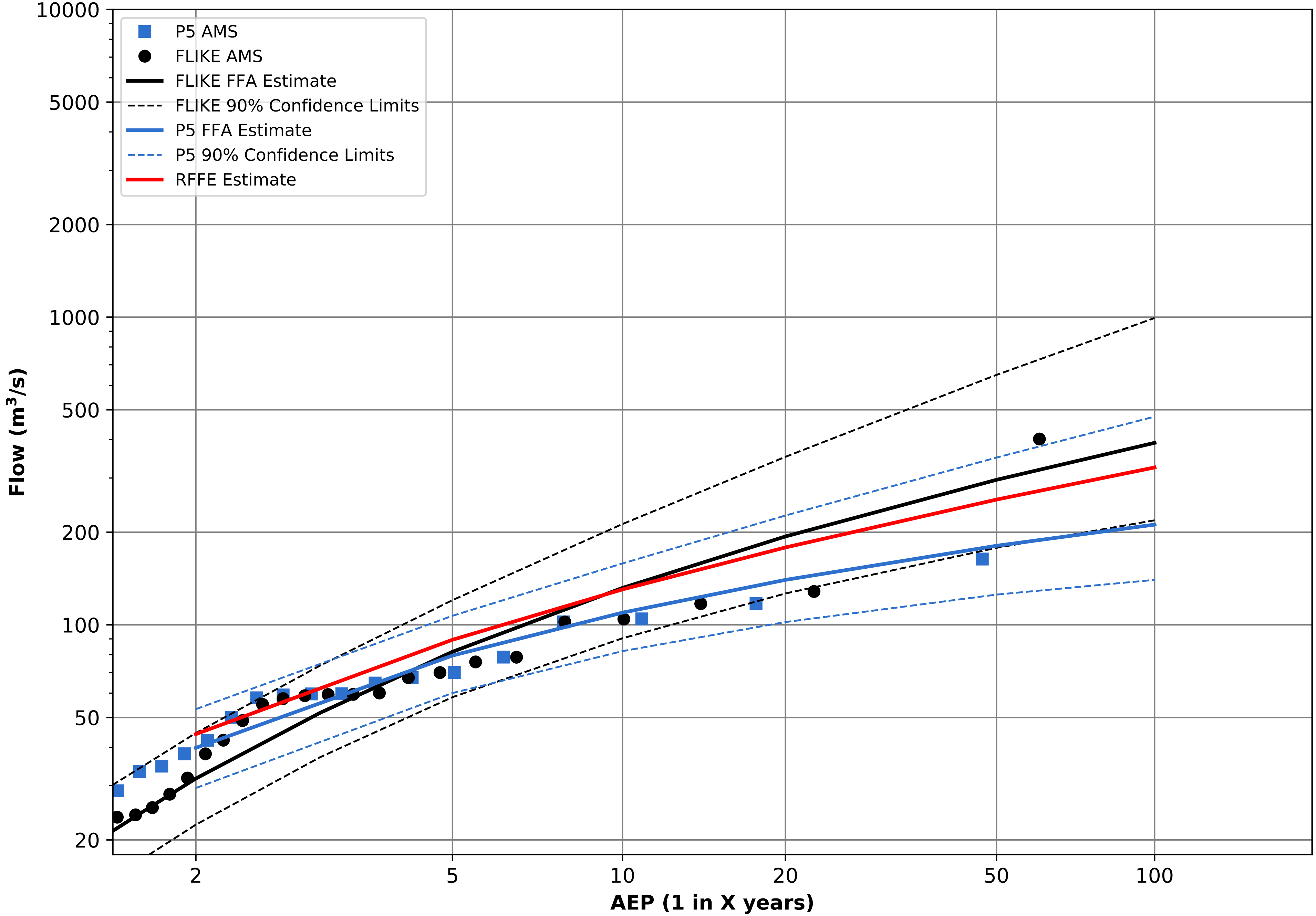
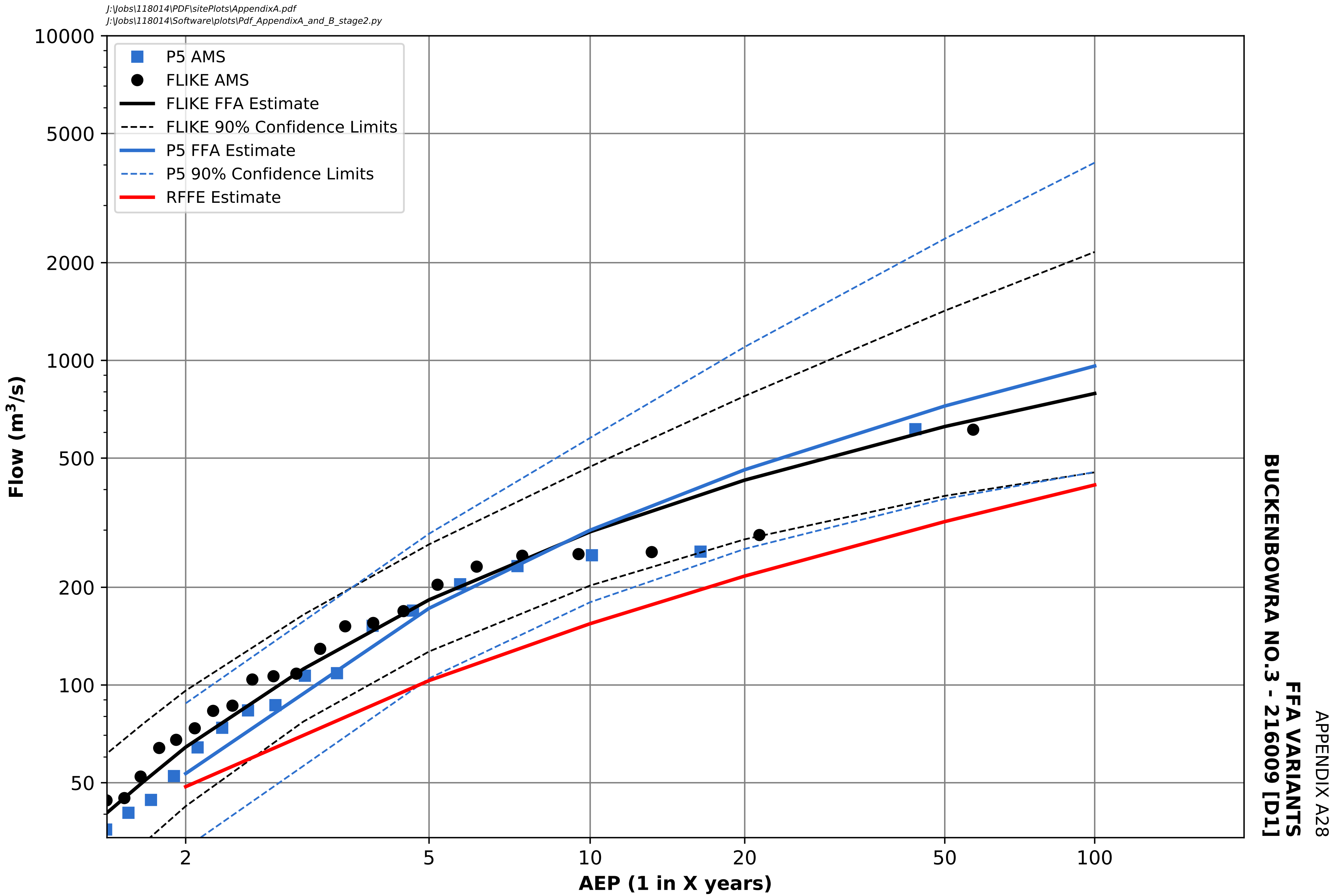


YARRAMUNDI - 401017 [C6]
FFA VARIANTS
APPENDIX A27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P5 AMS
FLIKE AMS
FLIKE FFA Estimate
FLIKE 90% Confidence Limits
P5 FFA Estimate
P5 90% Confidence Limits
RFFE Estimate
Flow (m³/s)
AEP (1 in X years)
10000
5000
2000
1000
500
200
100
50
2
5
10
20
50
100
BUCKENBOWRA NO.3 - 216009 [D1]
FFA VARIANTS
APPENDIX A28

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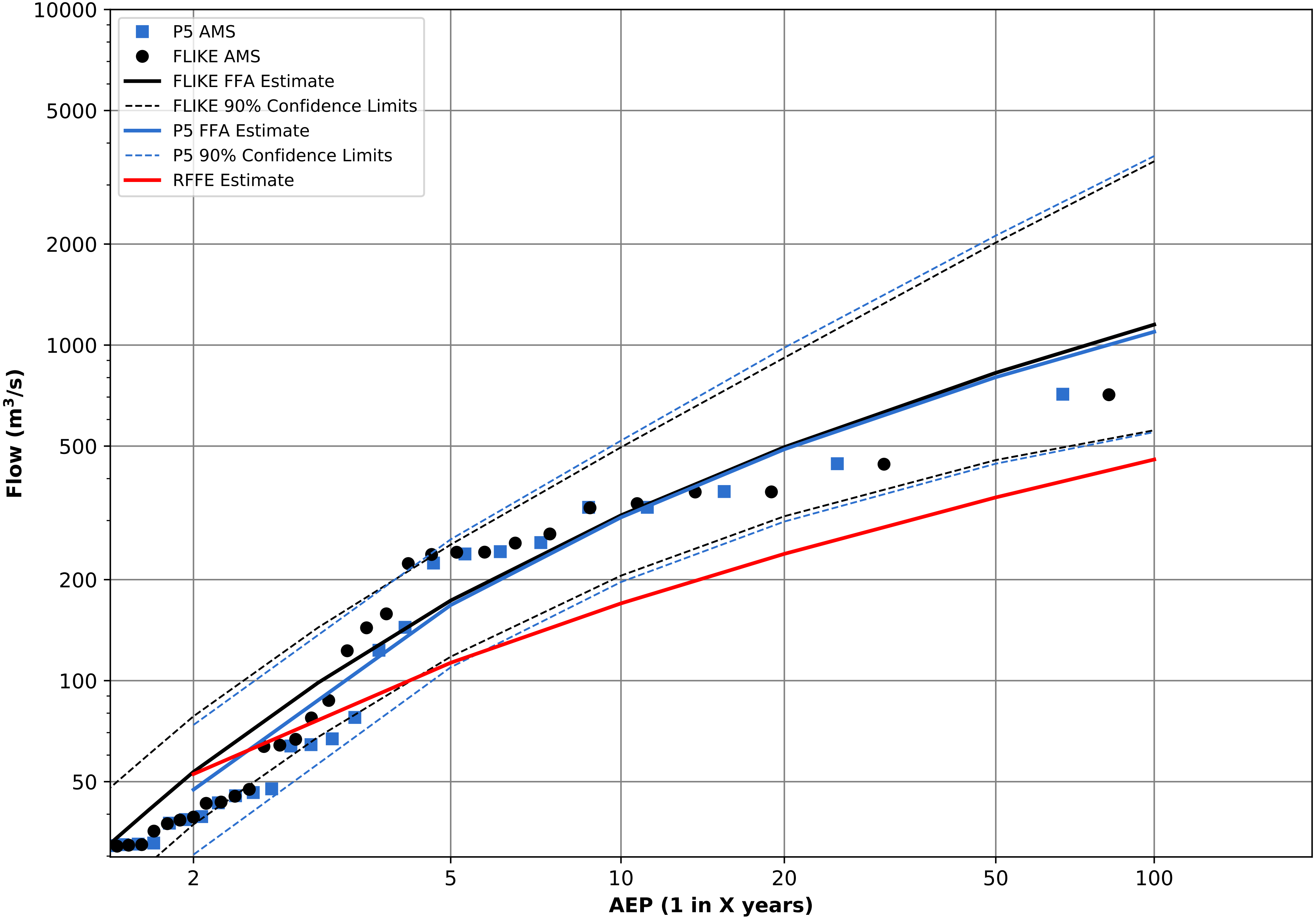
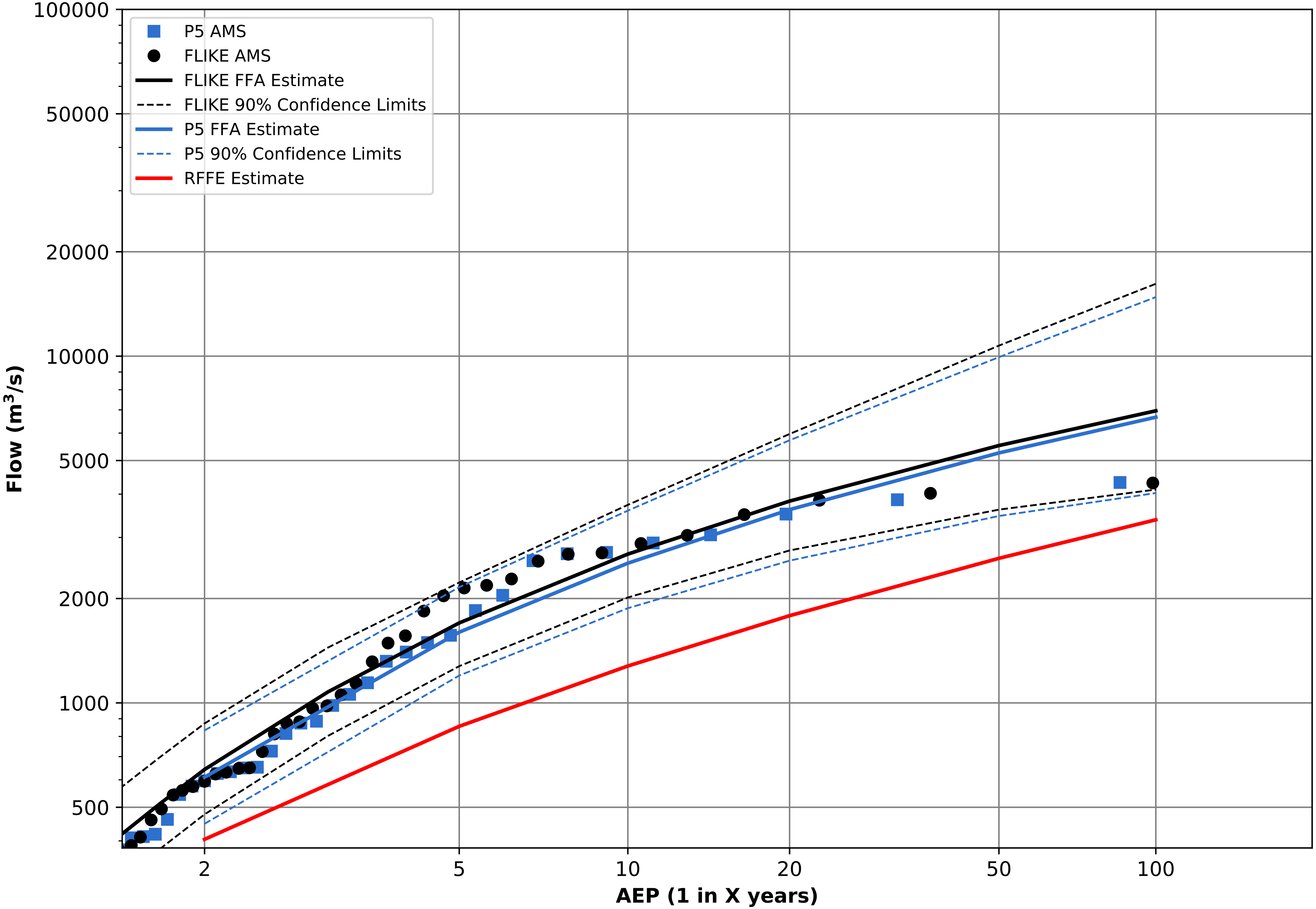
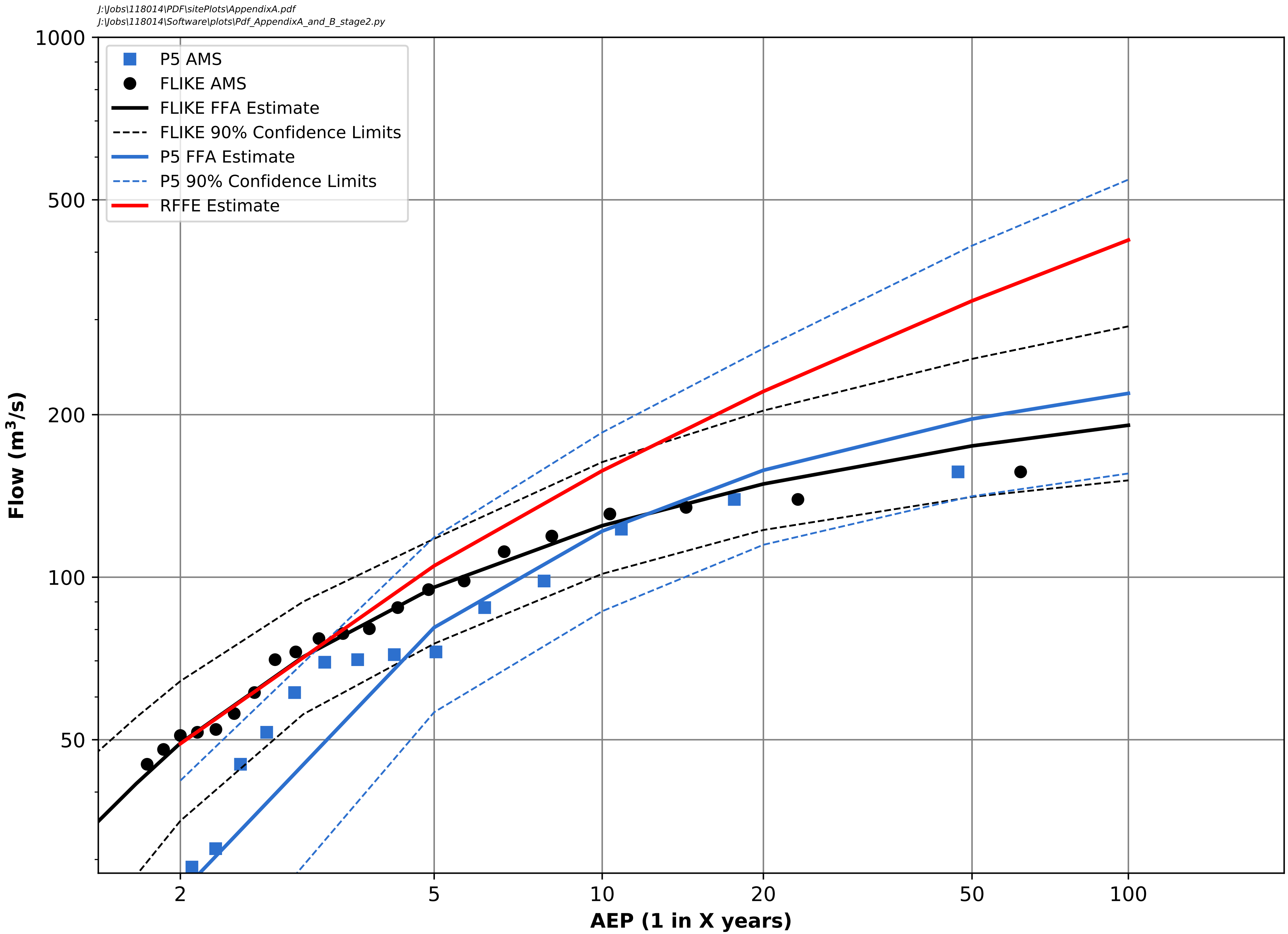


FFA VARIANTS
FALLS CK - 216004 [D3]



BROOMAN - 216002 [D4]
FFA VARIANTS
APPENDIX A30



BUNGONIA - 215014 [D5]
FFA VARIANTS
APPENDIX A31

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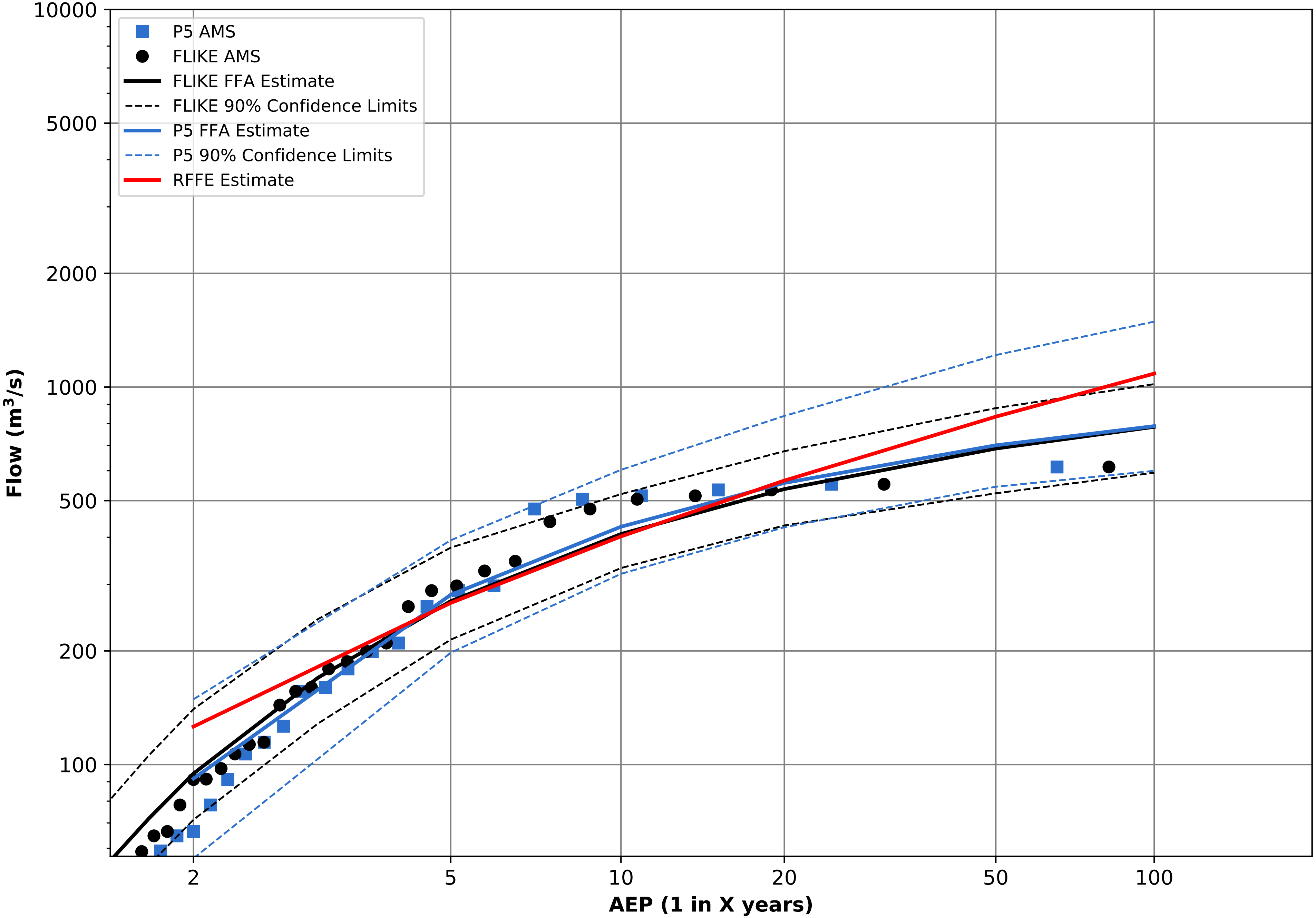

KADOONA - 215008 [D6]
FFA VARIANTS

APPENDIX A32

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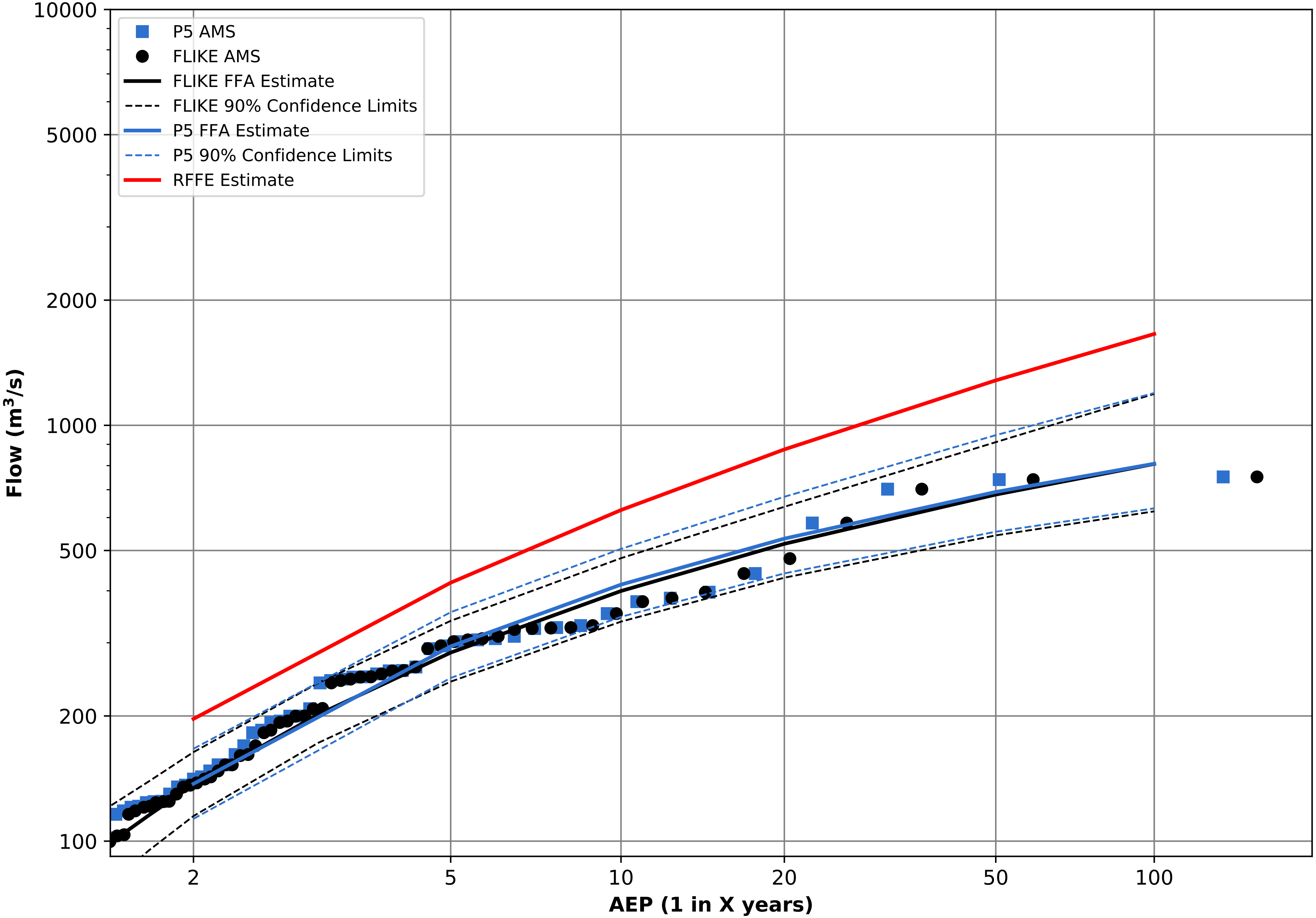

APPENDIX A33

FFA VARIANTS

HOCKEYS - 215004 [D7]

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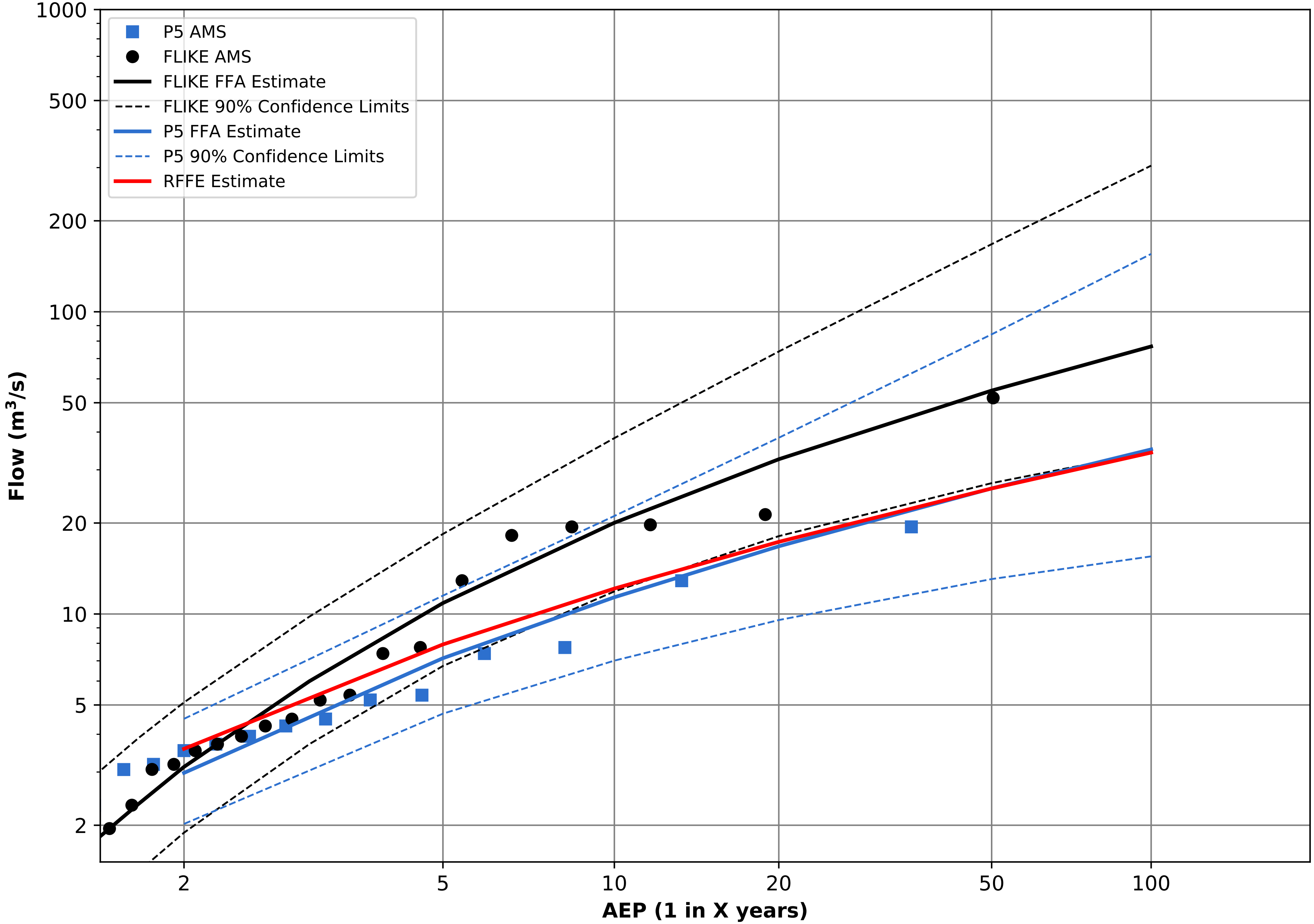
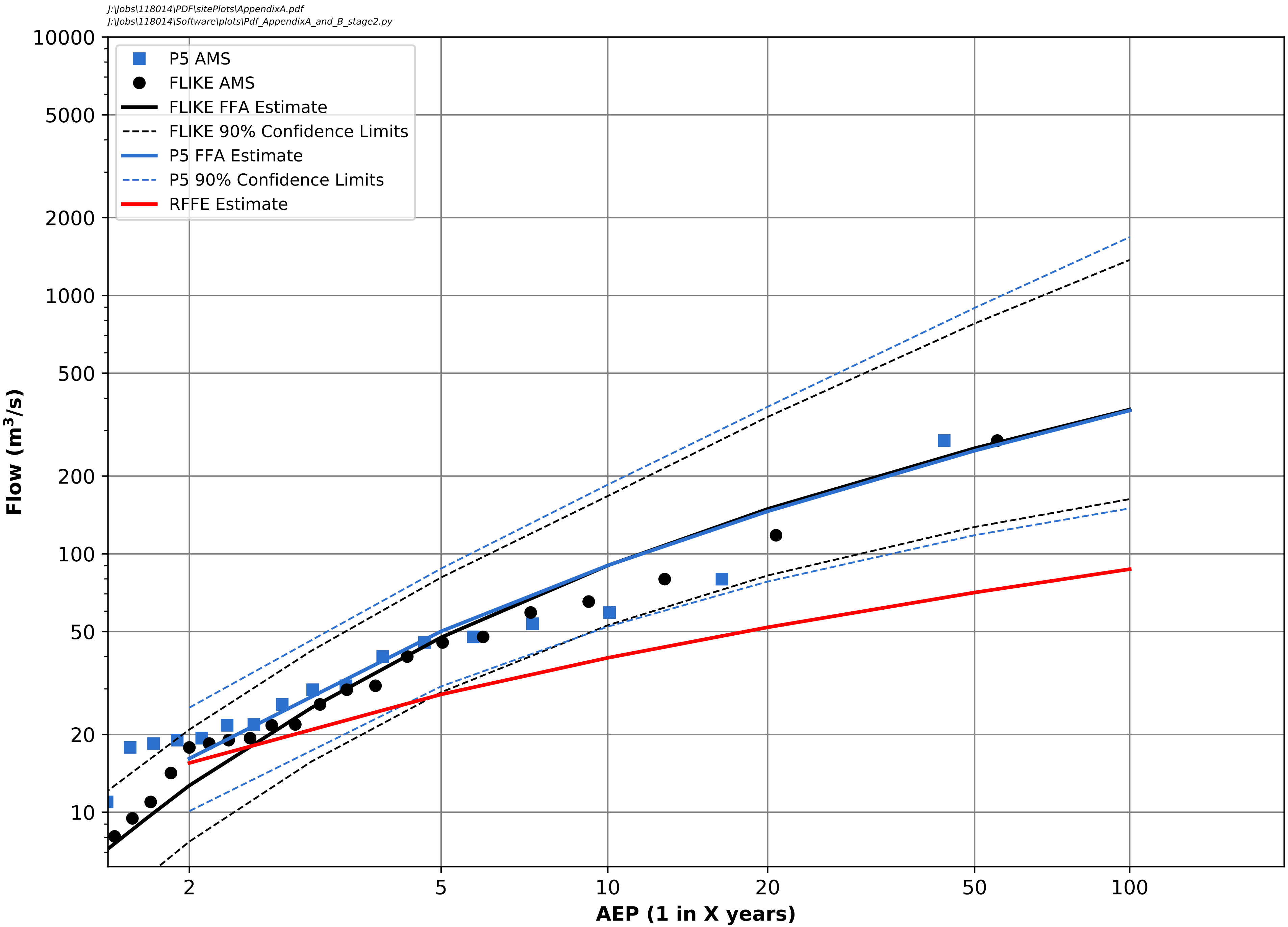


WHITE HILL - 410160 [E1]
FFA VARIANTS
APPENDIX A34



BOOK BOOK - 410156 [E2]

FFA VARIANTS

APPENDIX A35

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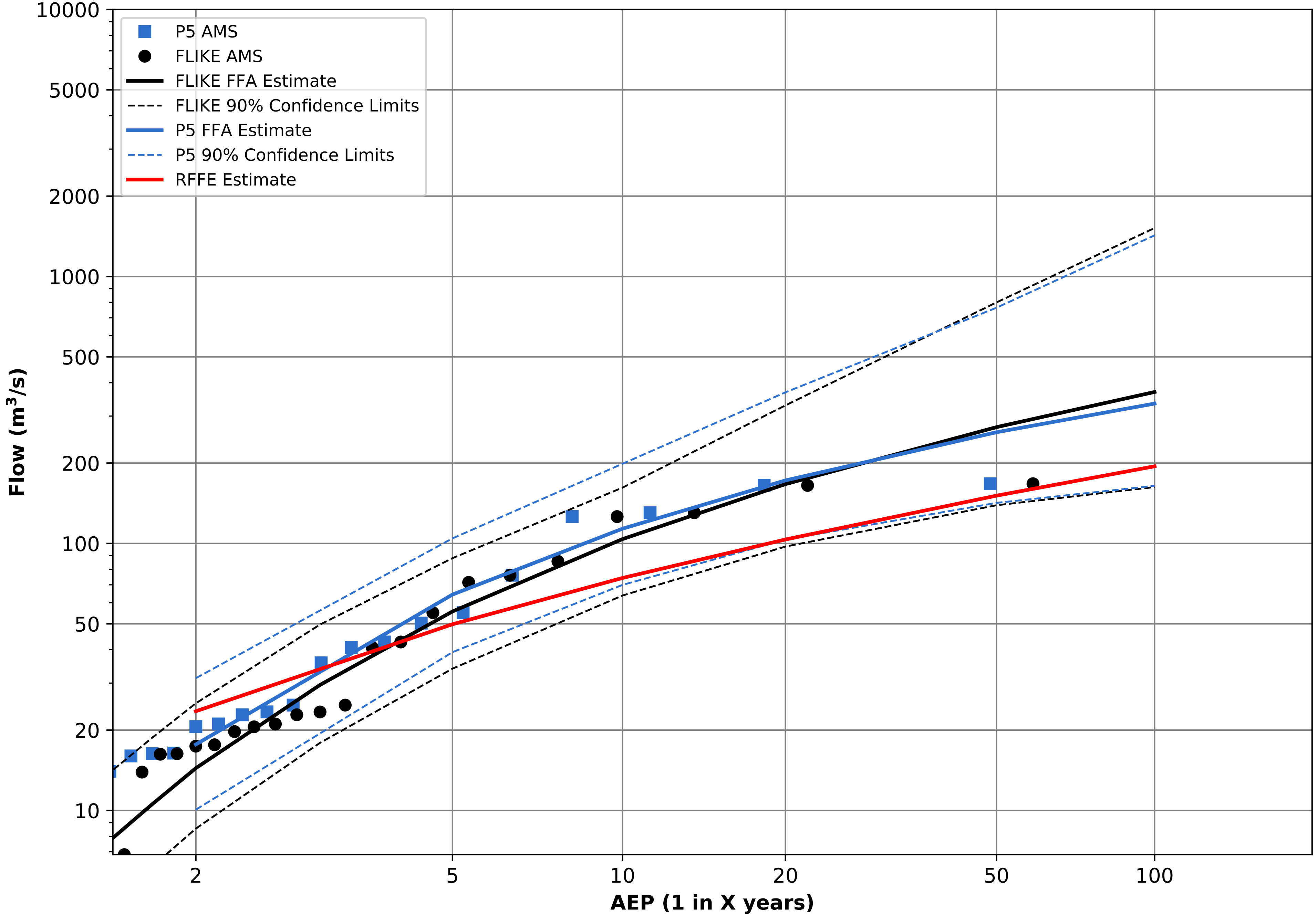
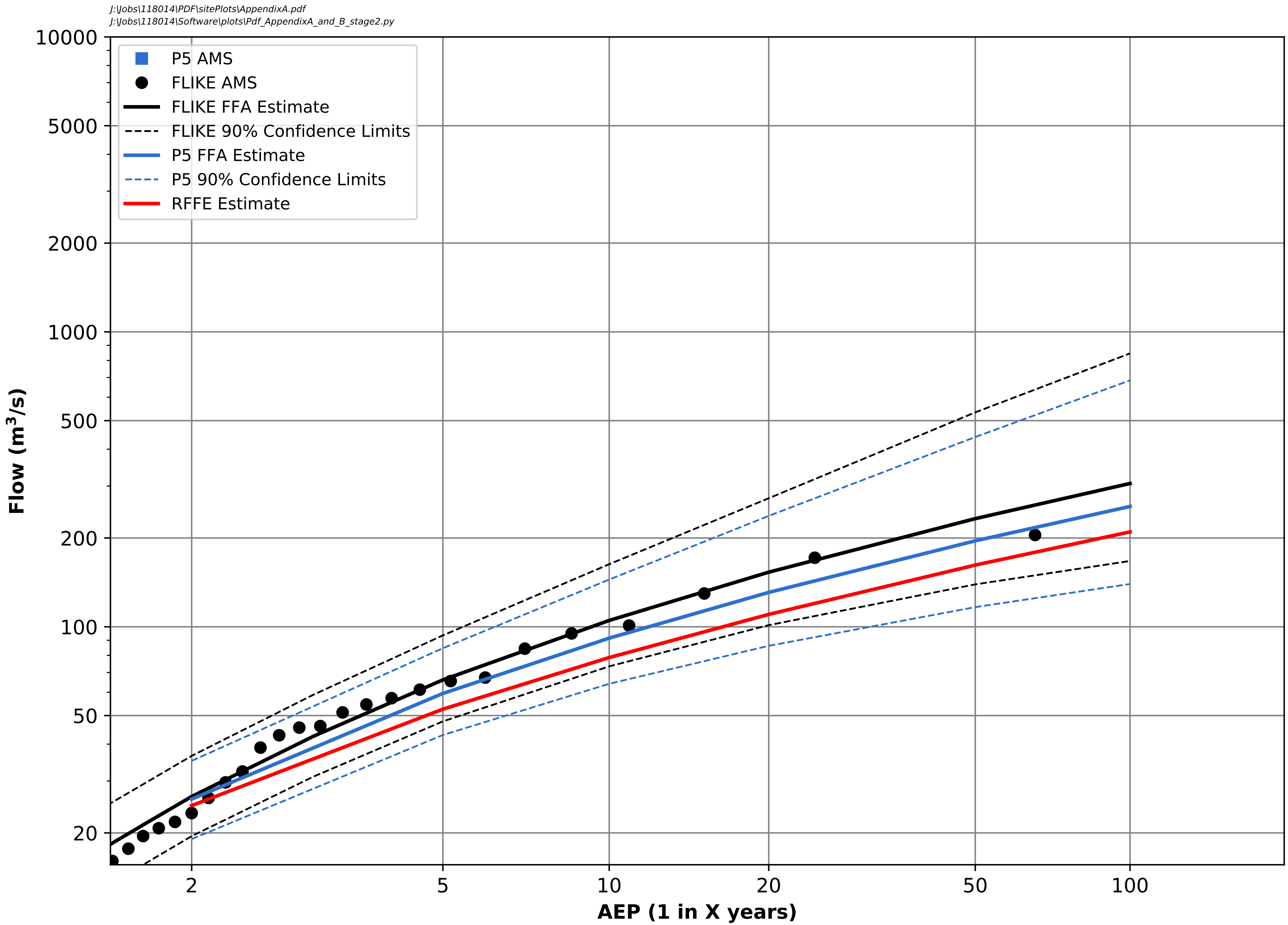


APPENDIX A36
FFA VARIANTS
MICHELAGO - 410141 [E3]



FFA VARIANTS
BUTMAROO - 411003 [E4]

APPENDIX A37

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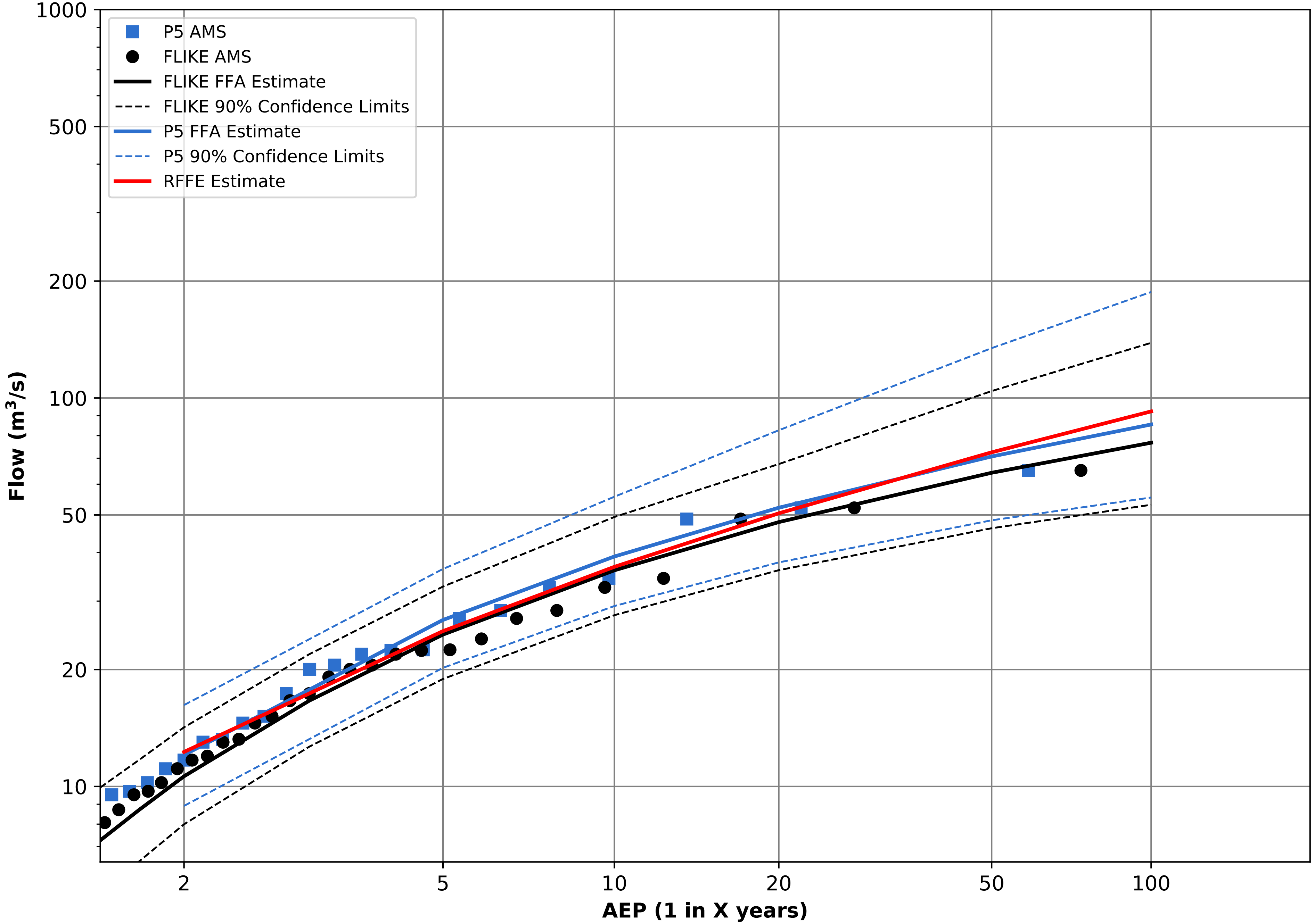

WYANGLE - 410114 [E5]
FFA VARIANTS
APPENDIX A38

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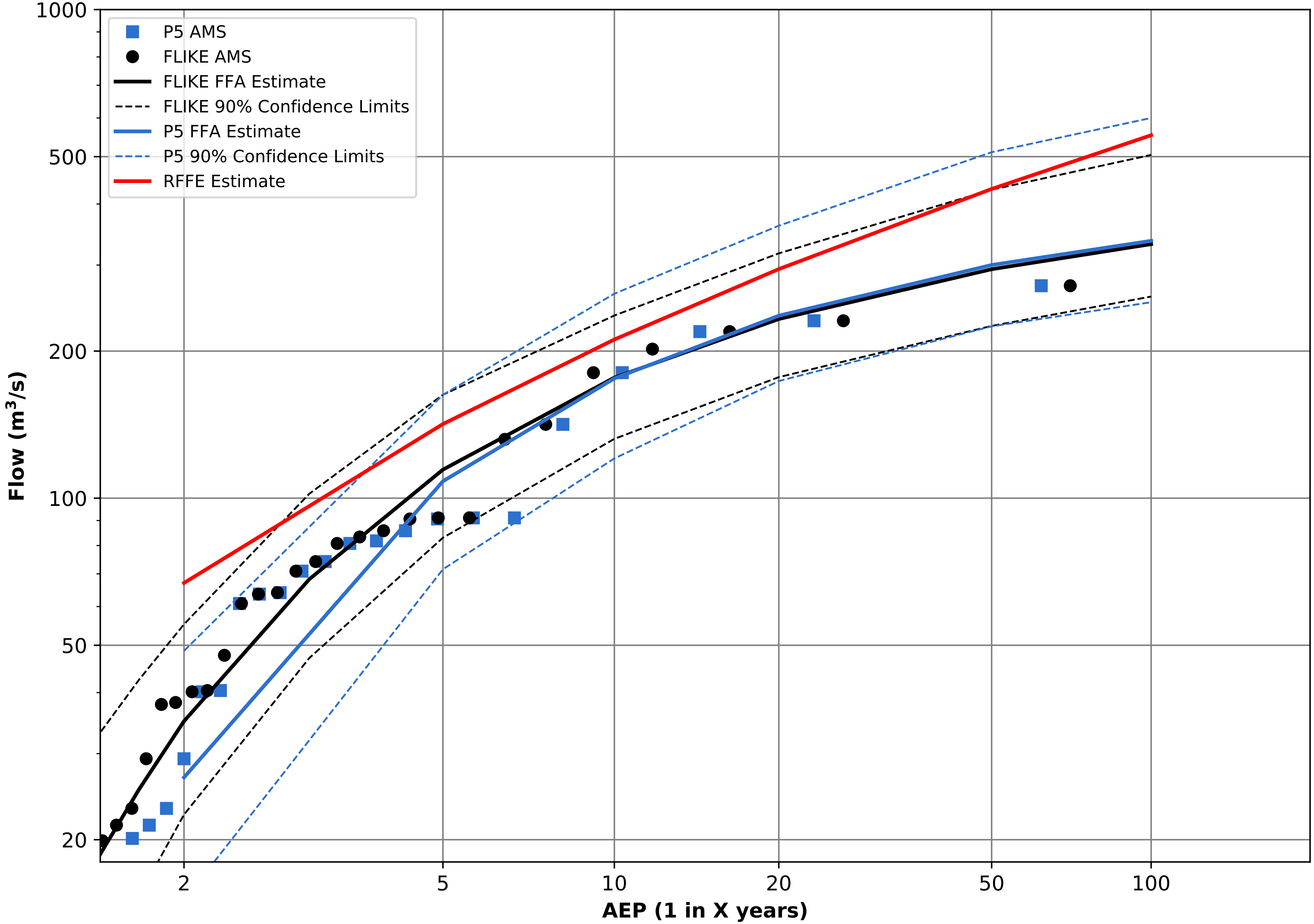
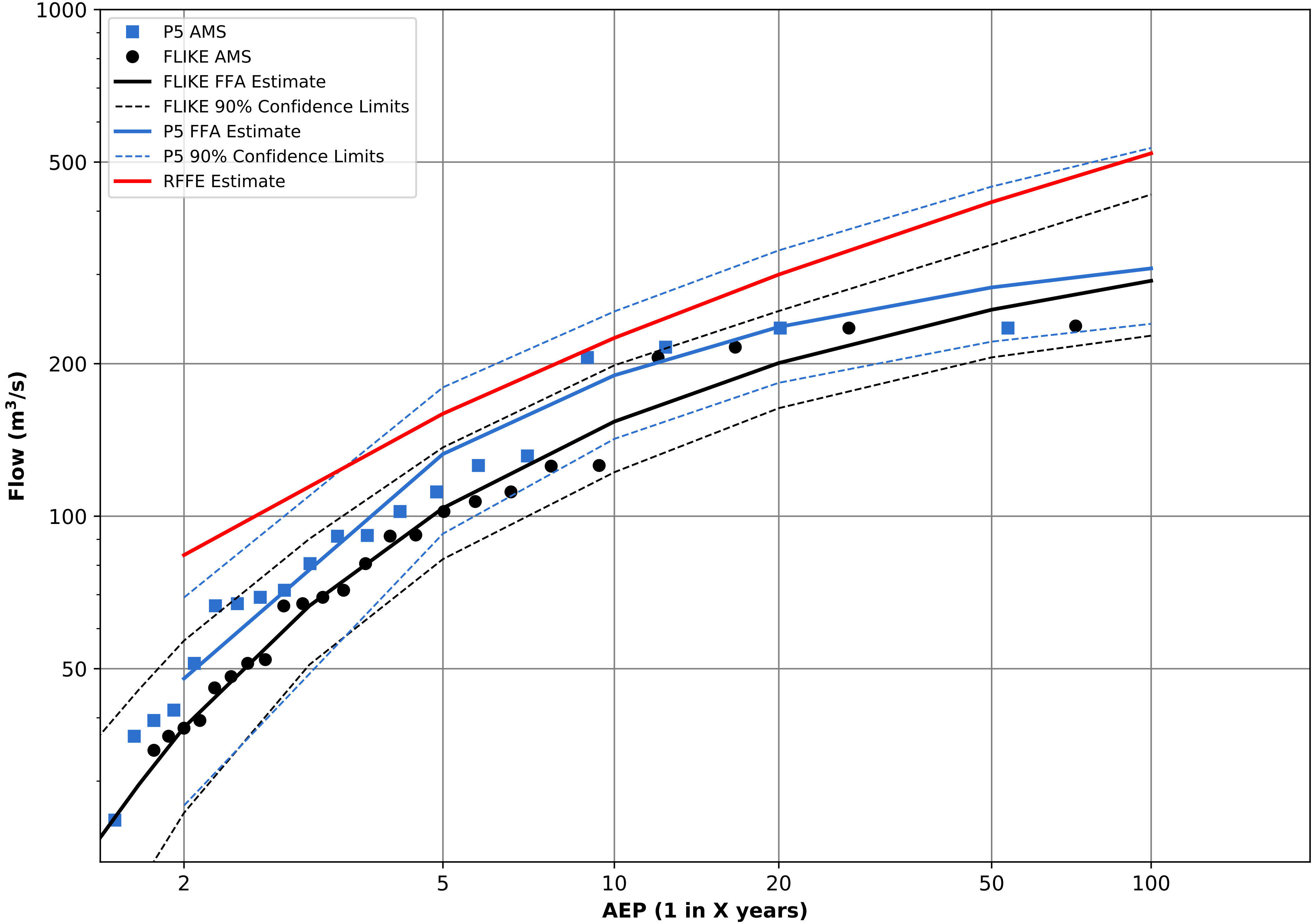
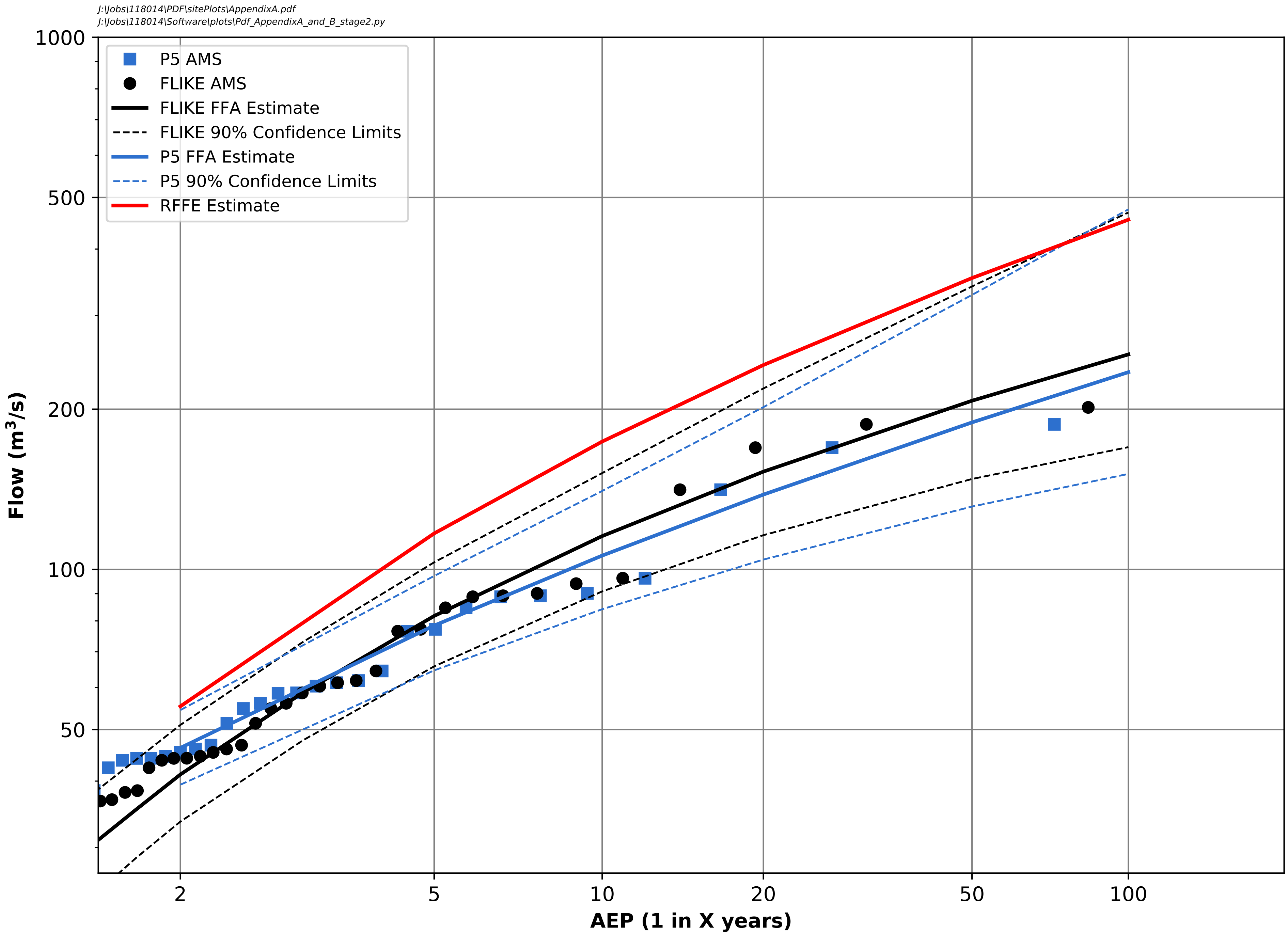


JERANGLE RD - 410076 [E6]
FFA VARIANTS
APPENDIX A39



MOUNTAIN CK - 410107 [E7]
FFA VARIANTS
APPENDIX A40



DARBALARA - 410038 [E8]

FFA VARIANTS

APPENDIX A41

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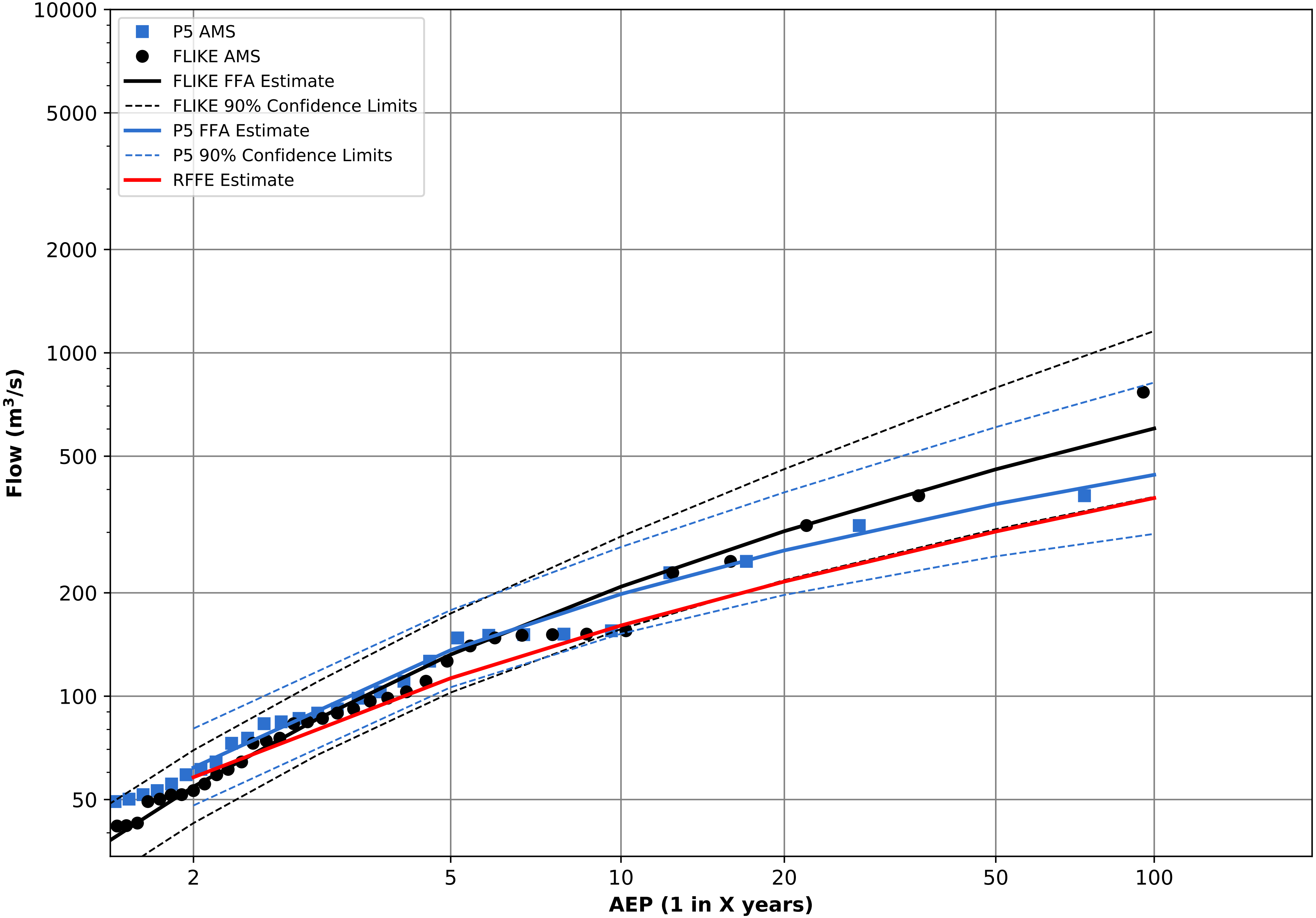

BRINDABELLA (NO.2&NO.3-CAB - 410088 [E9]

FFA VARIANTS

APPENDIX A42

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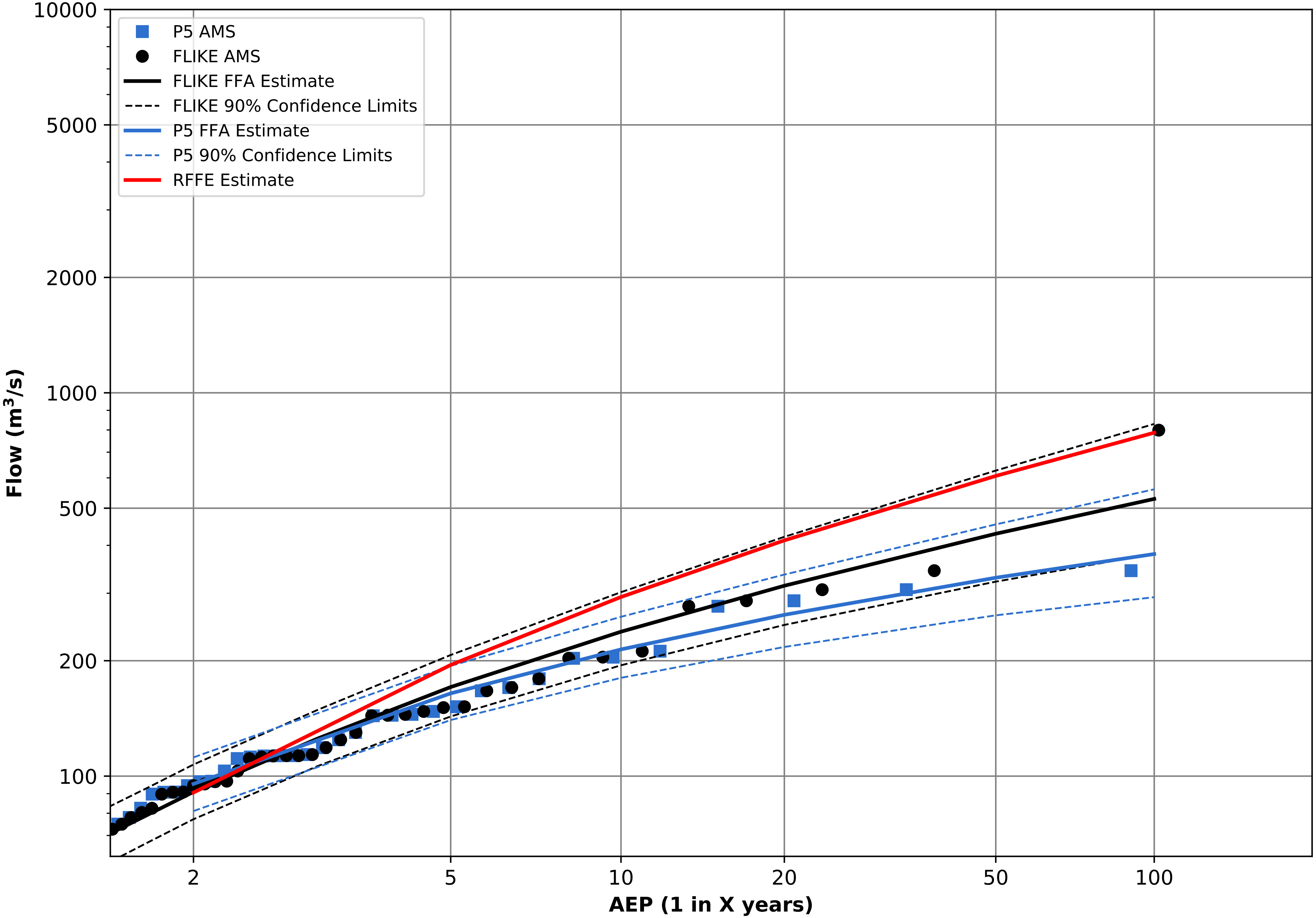

LACMALAC - 410057 [E10]
FFA VARIANTS
APPENDIX A43

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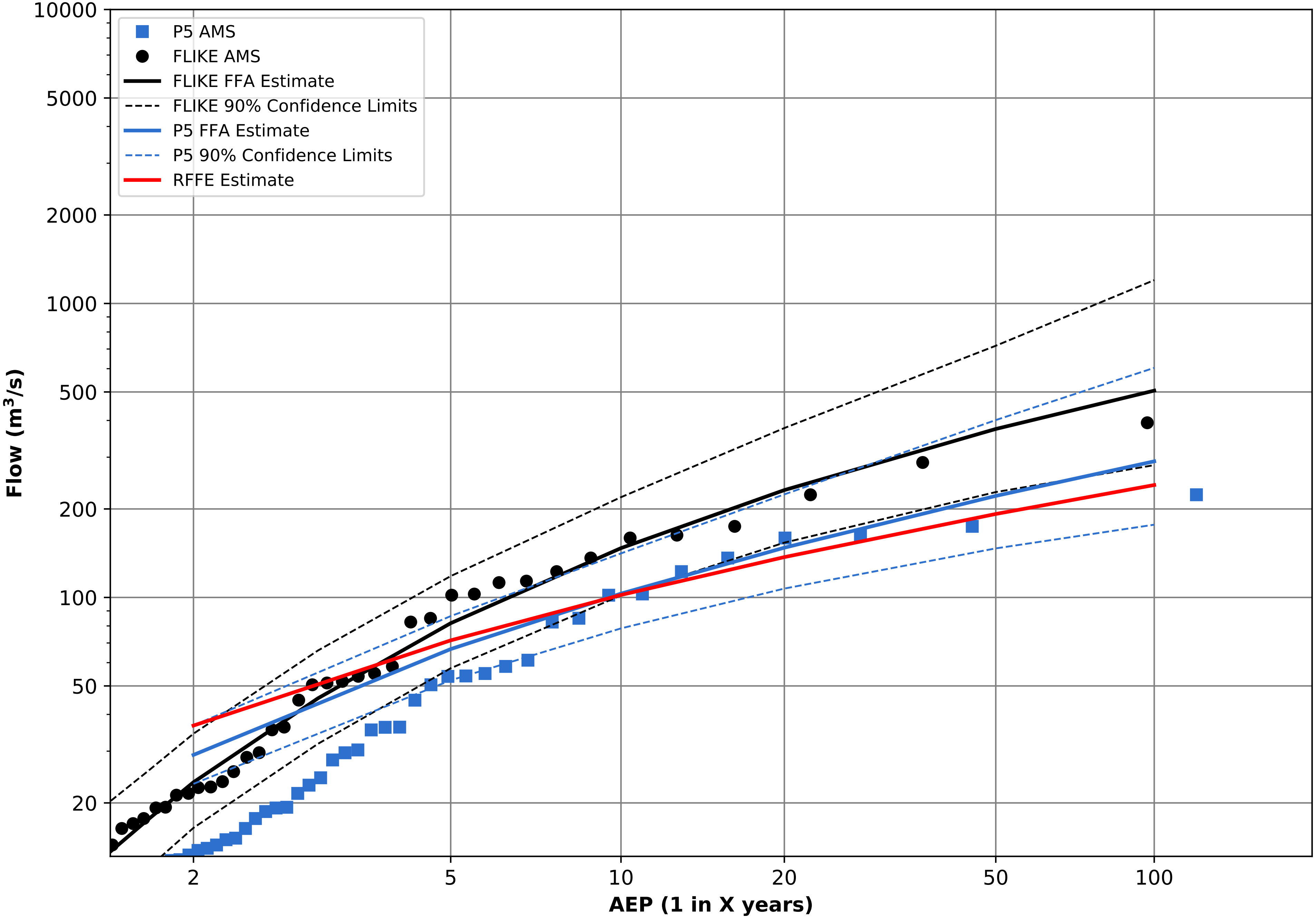

LADYSMITH - 410048 [E11]

FFA VARIANTS

APPENDIX A44

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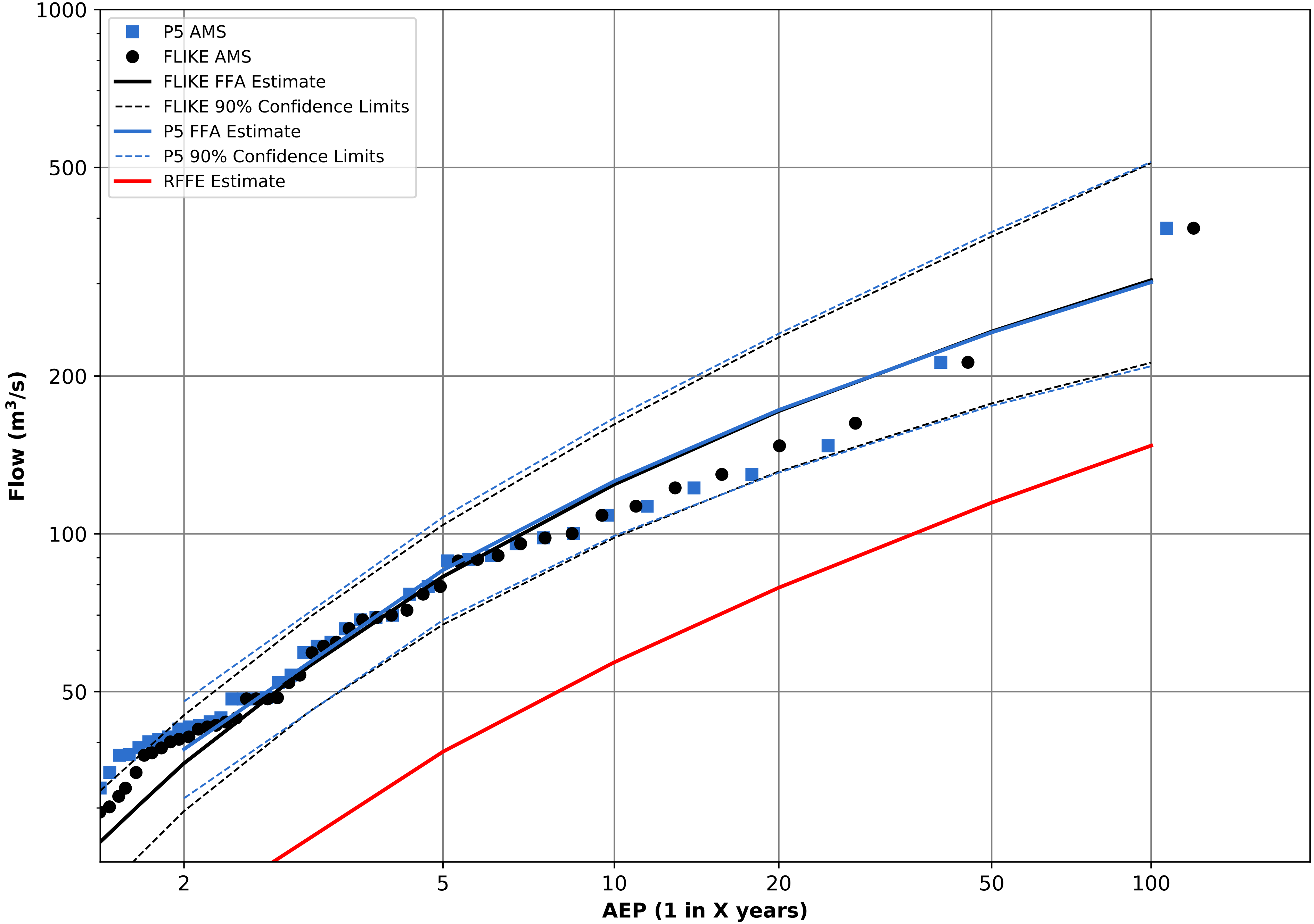
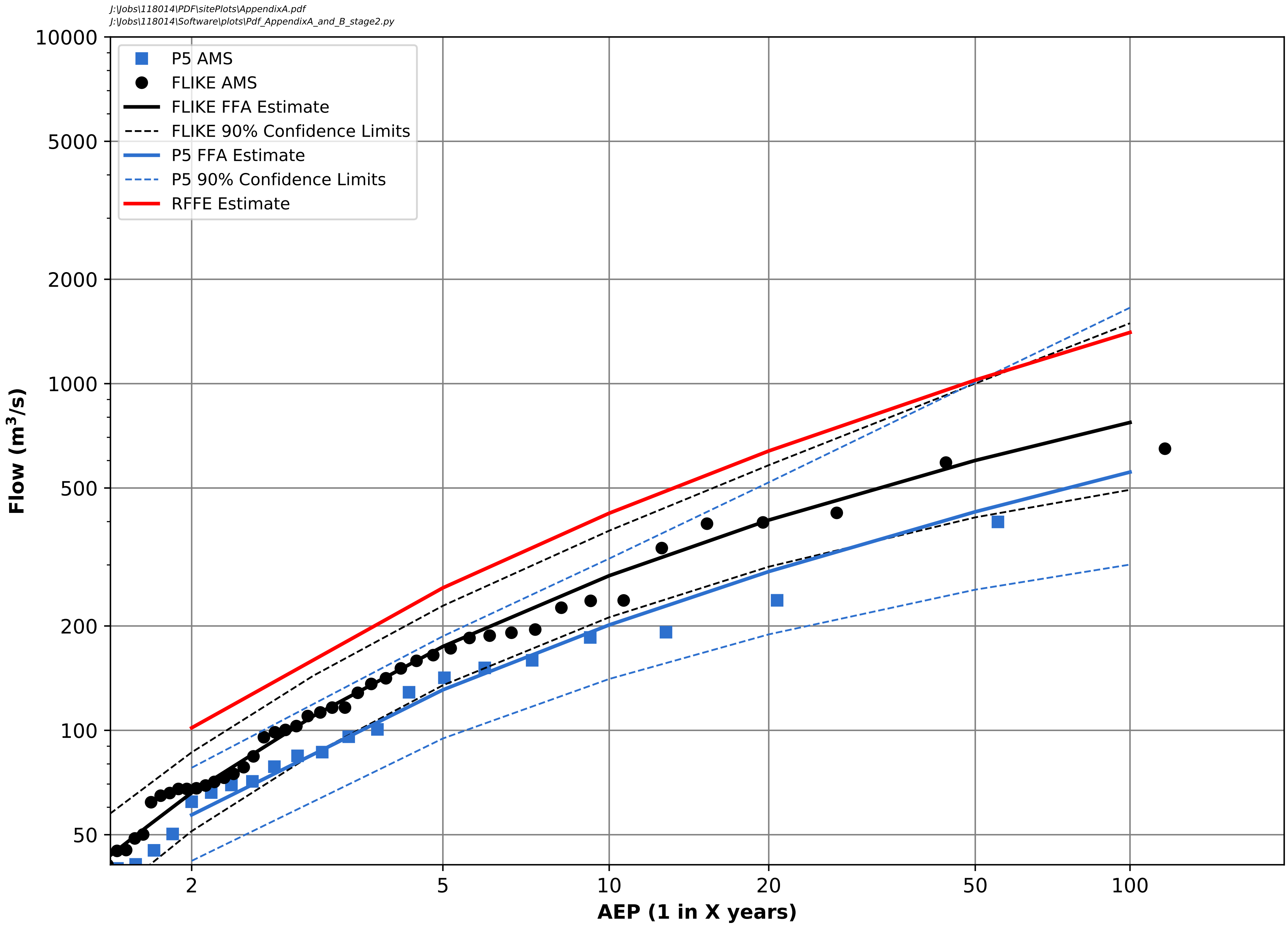
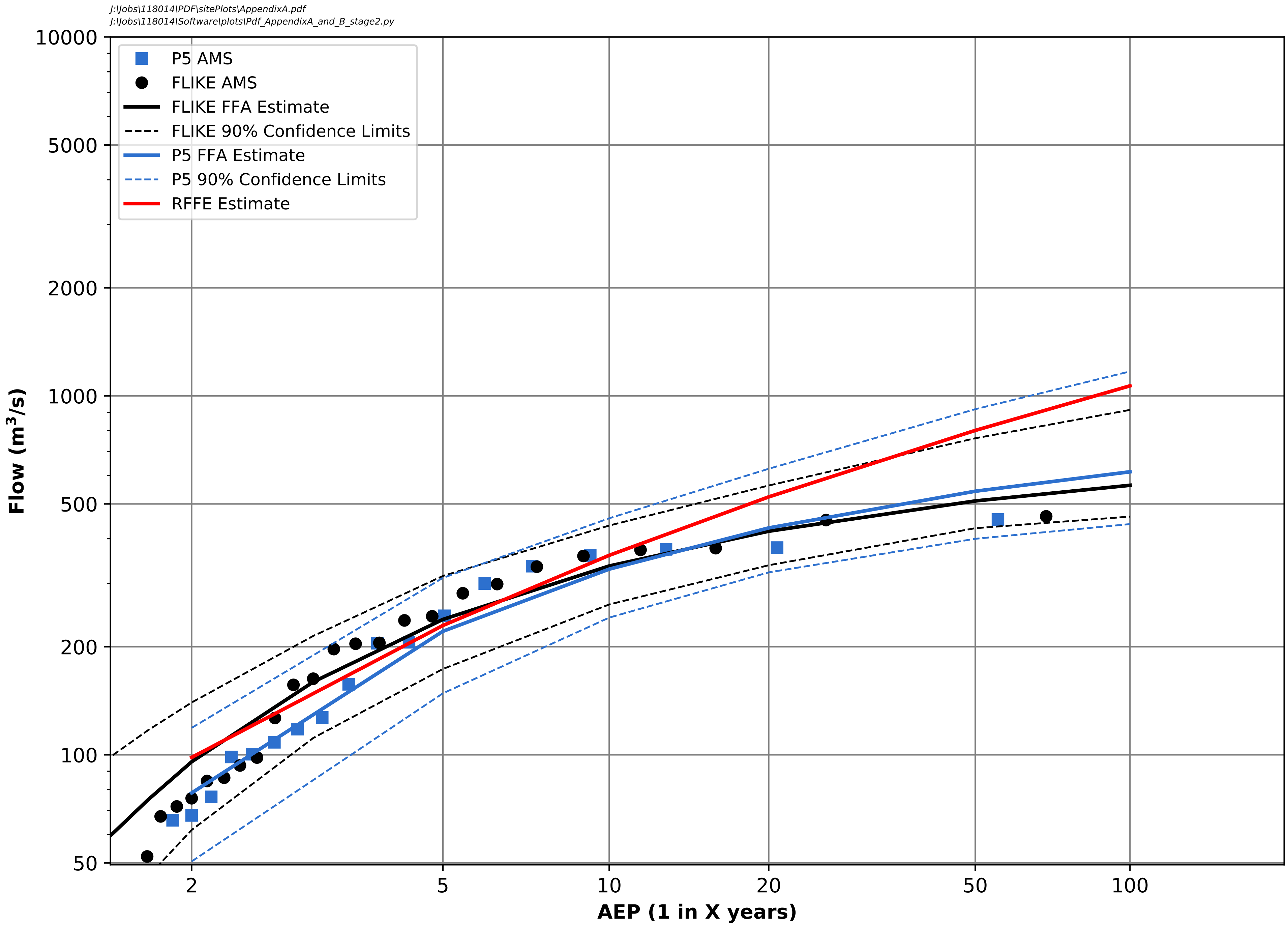


BATLOW RD - 410061 [E12]
FFA VARIANTS
APPENDIX A45

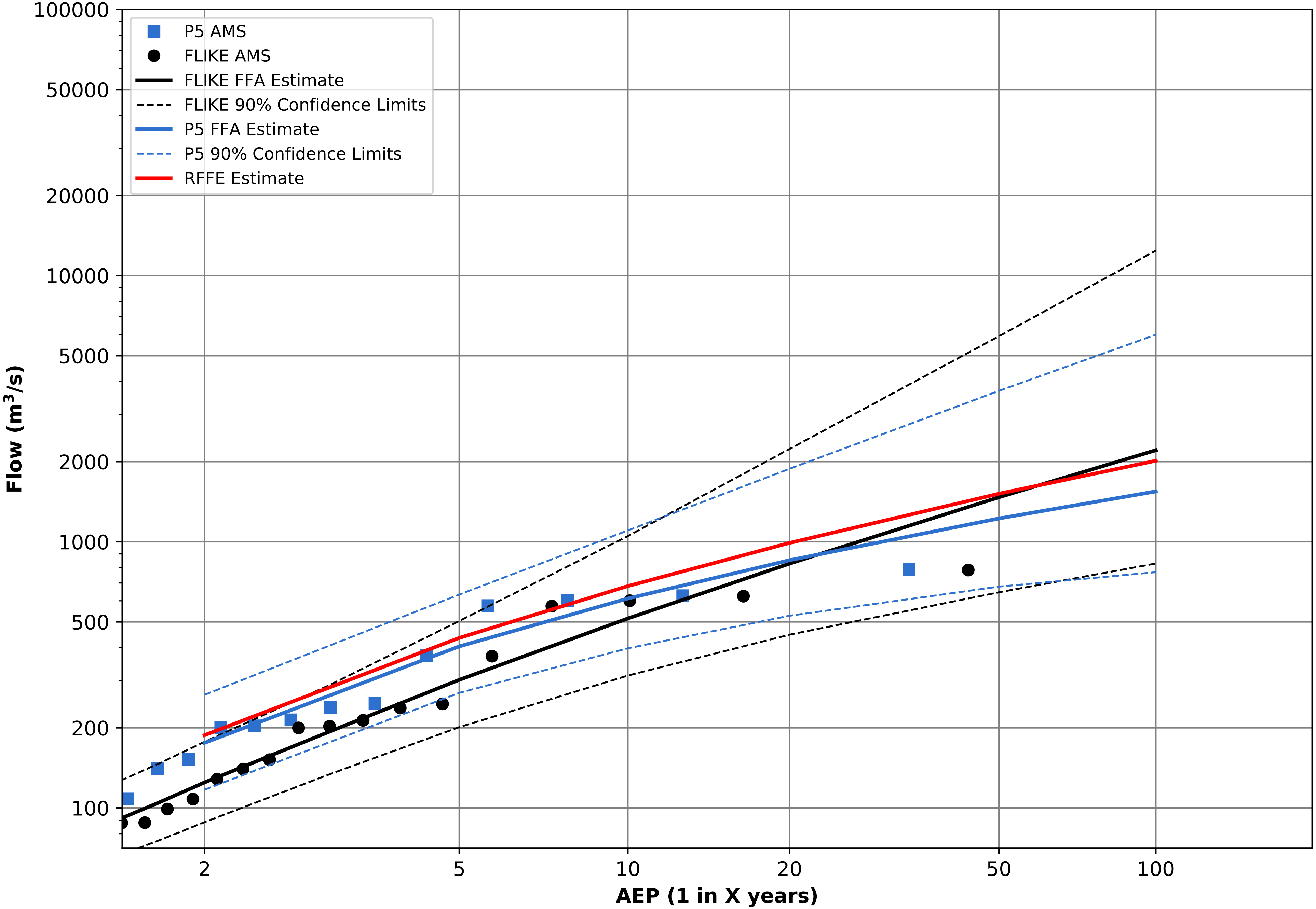


FFA VARIANTS
ALBION PARK - 214003 [F1]

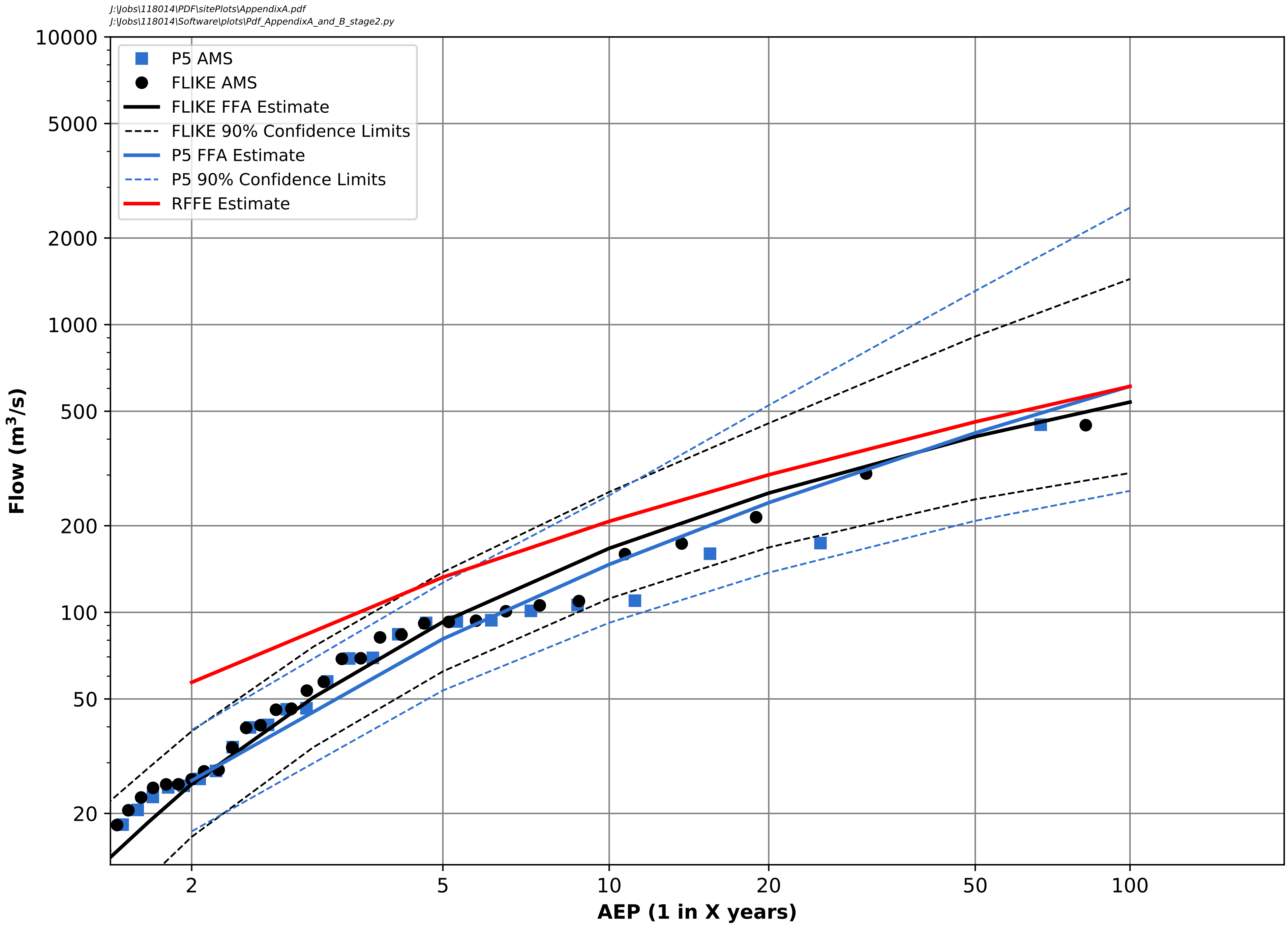
APPENDIX A46



WEDDERBURN - 213200 [F2]
FFA VARIANTS



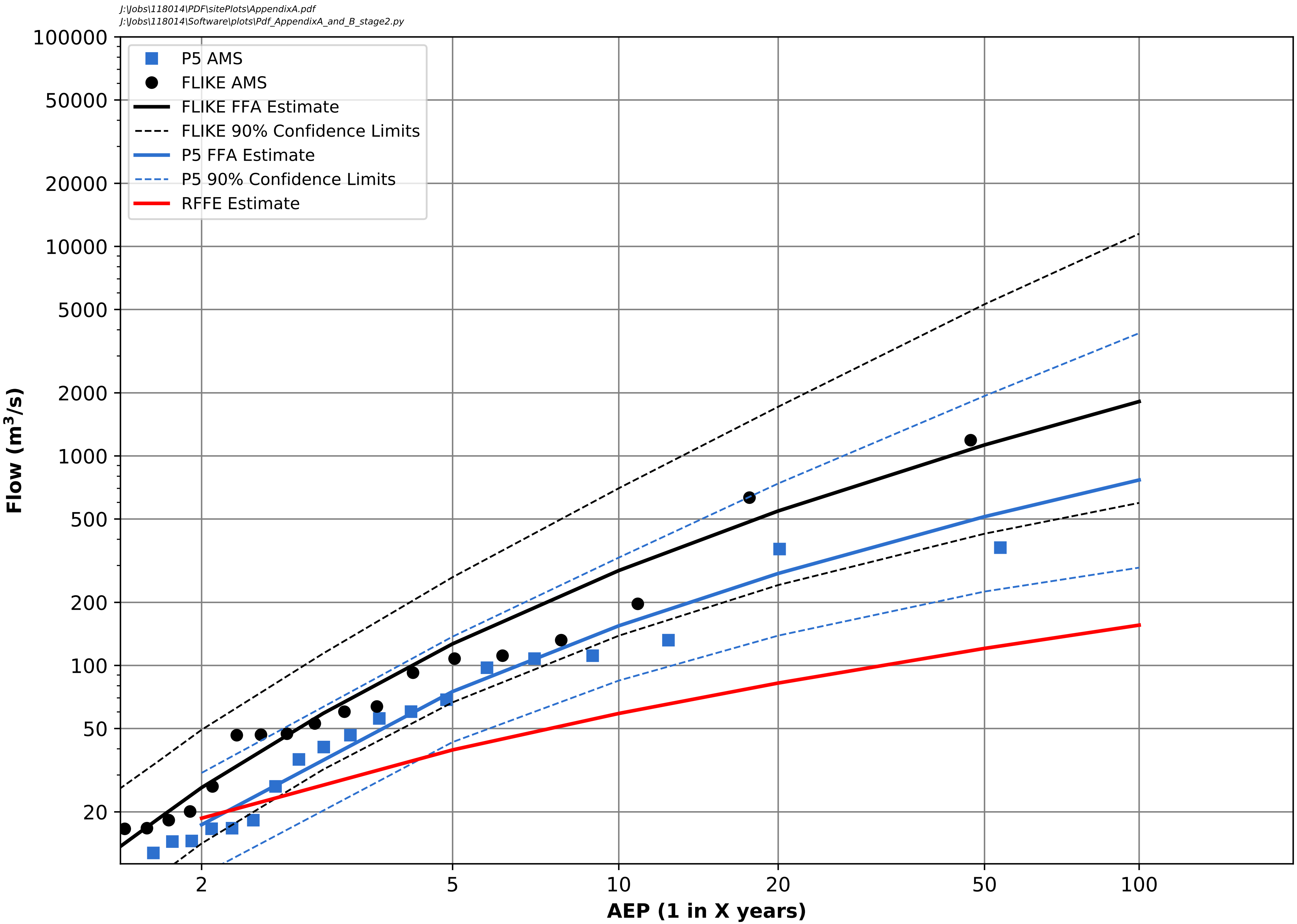
PARRAMATTA HOSPITAL - 213004 [F3]
FFA VARIANTS



MULGOA RD - 212320 [F4]

FFA VARIANTS

APPENDIX A49



POMEROY - 212040 [F5]

FFA VARIANTS

APPENDIX A50

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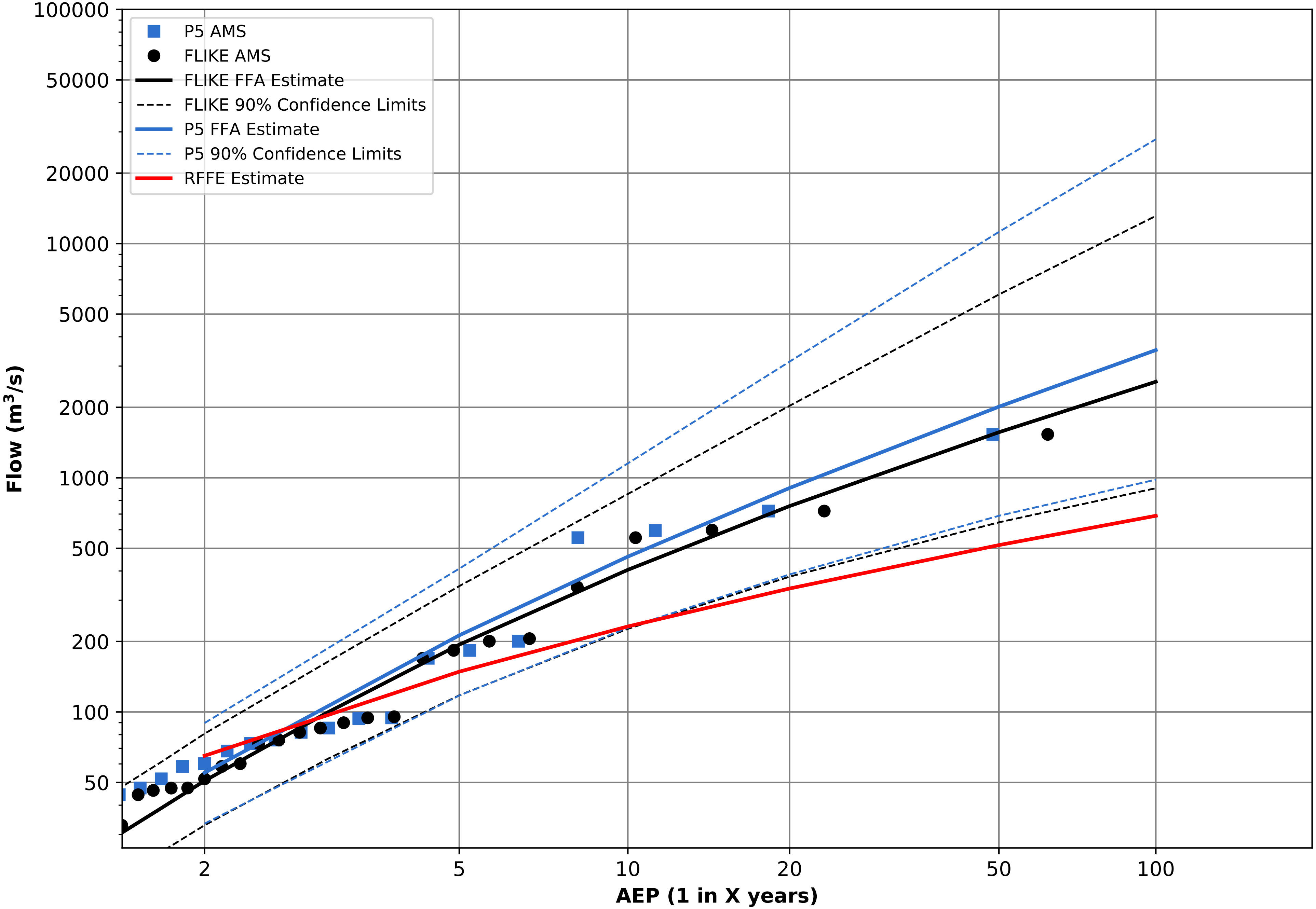

ISLAND HILL - 212045 [F6]

FFA VARIANTS

APPENDIX A51

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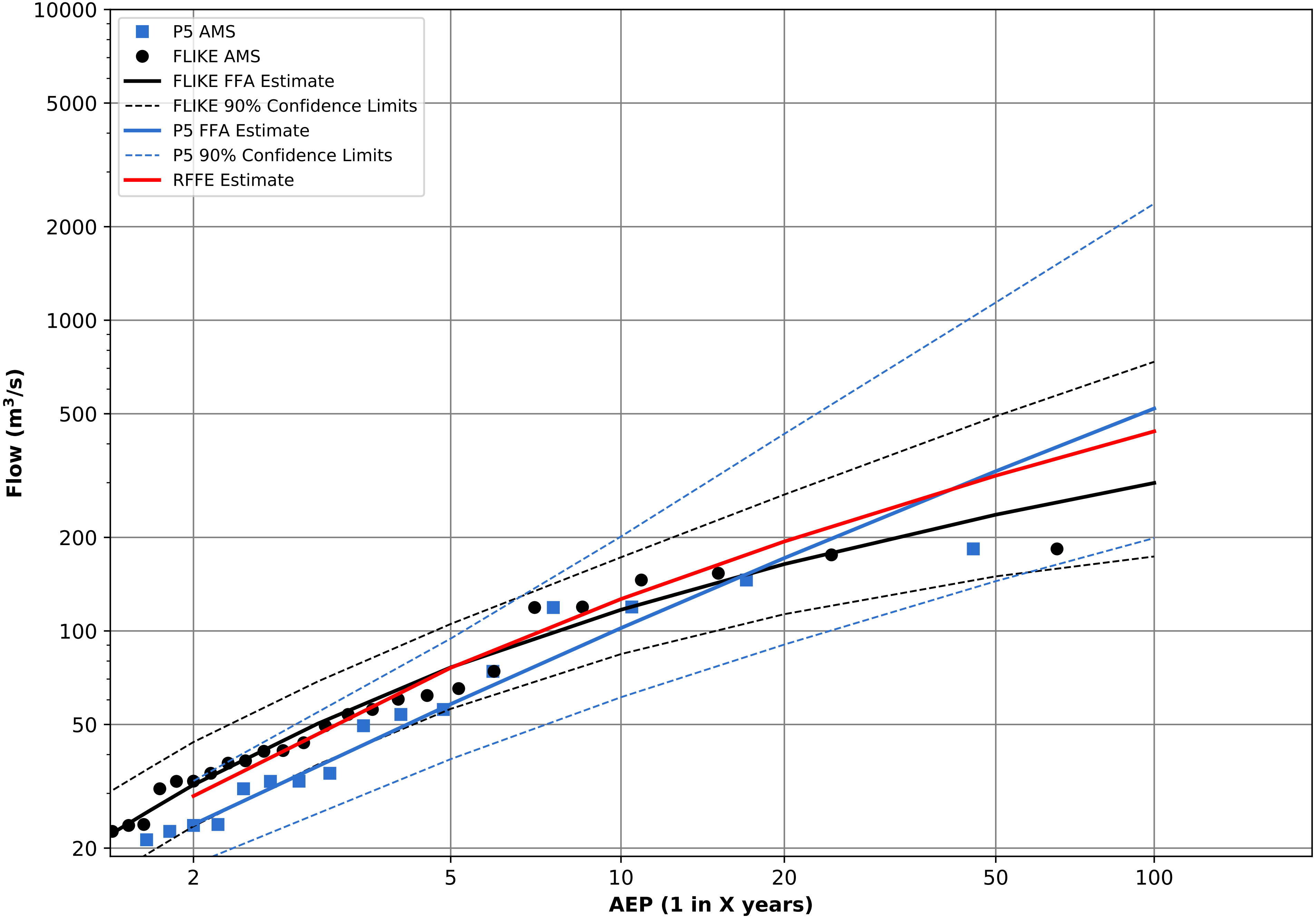

MOUNT WALKER - 212042 [F7]

FFA VARIANTS

APPENDIX A52

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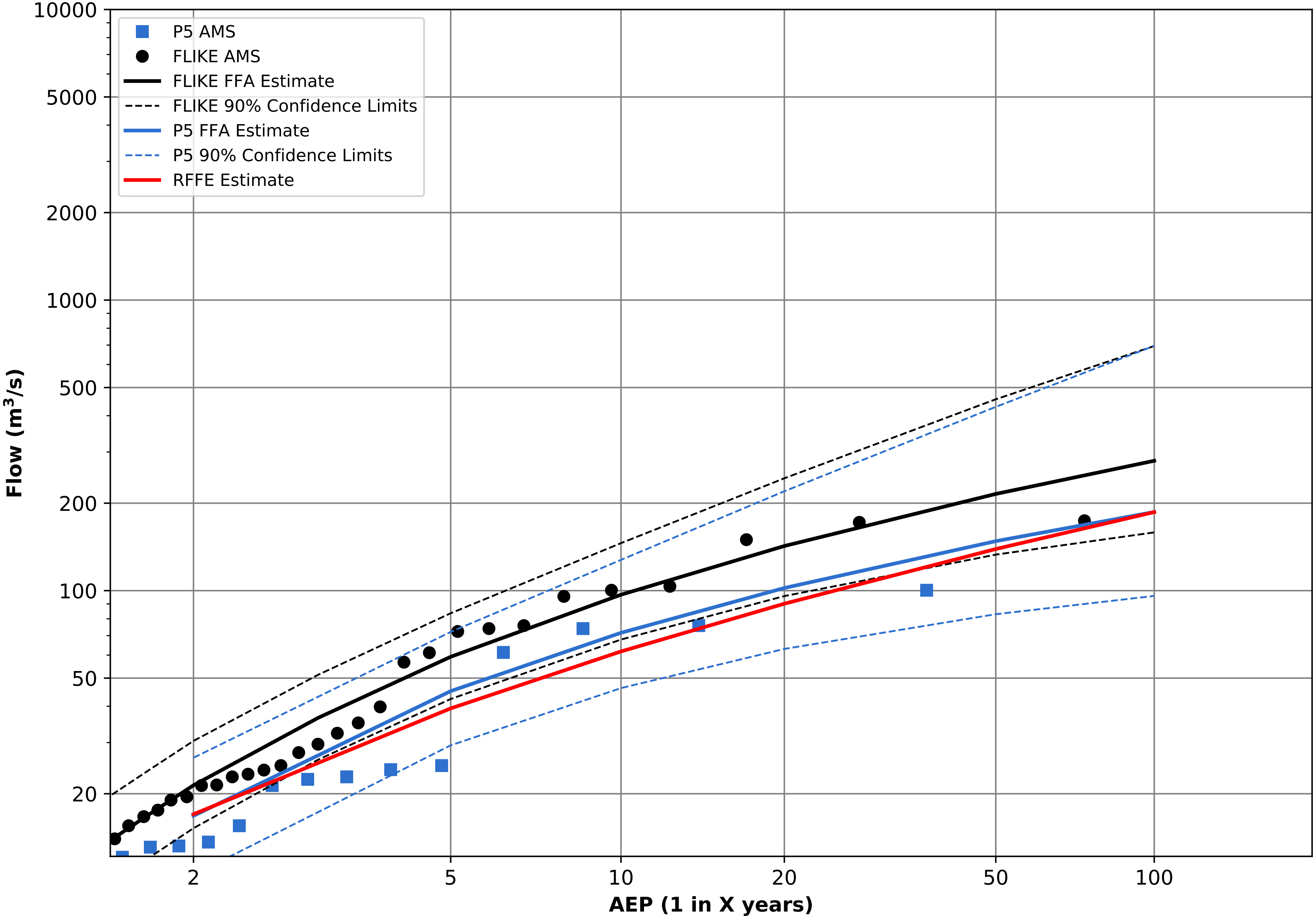

NARROW NECK - 212013 [F8]
FFA VARIANTS
APPENDIX A53

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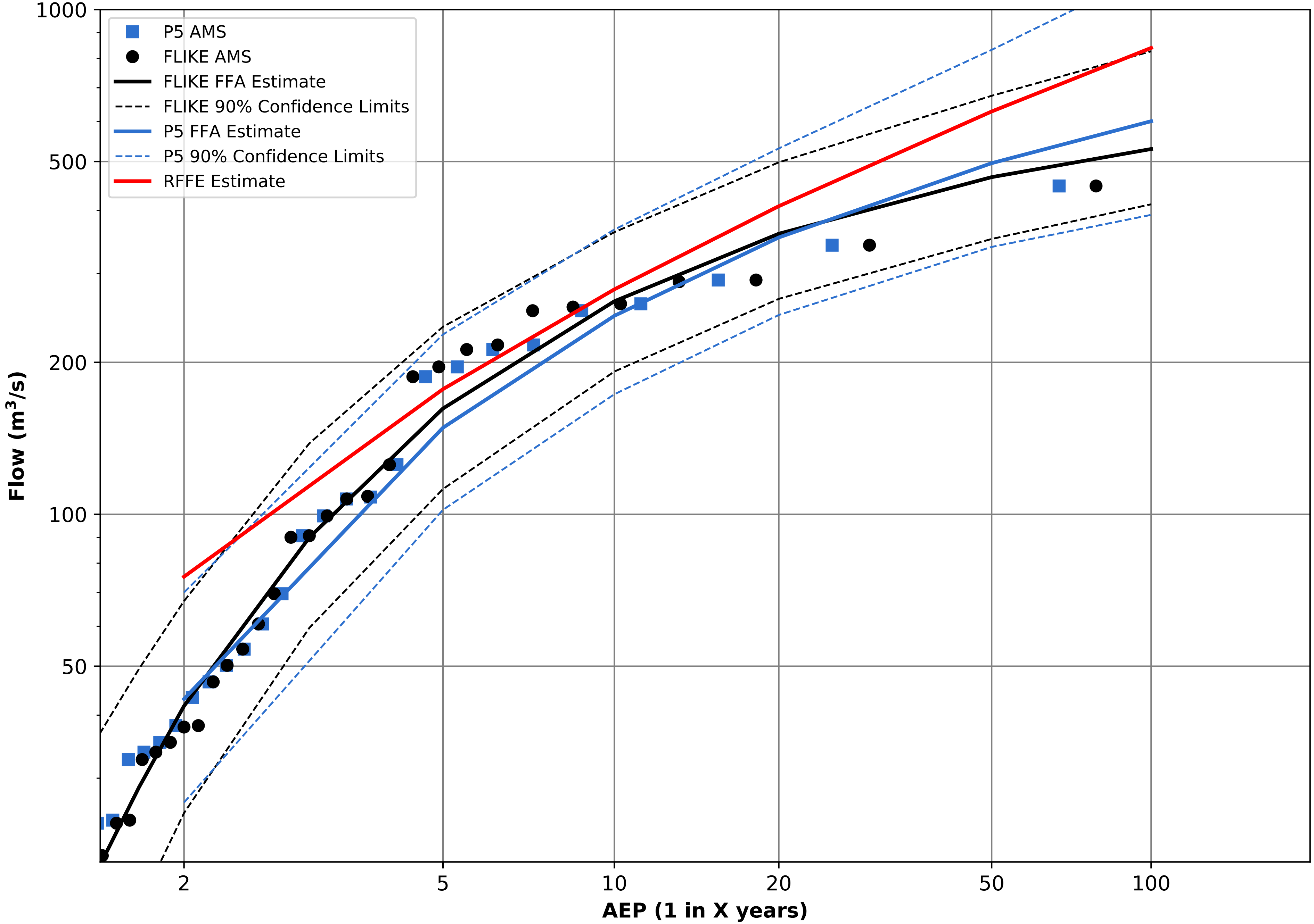
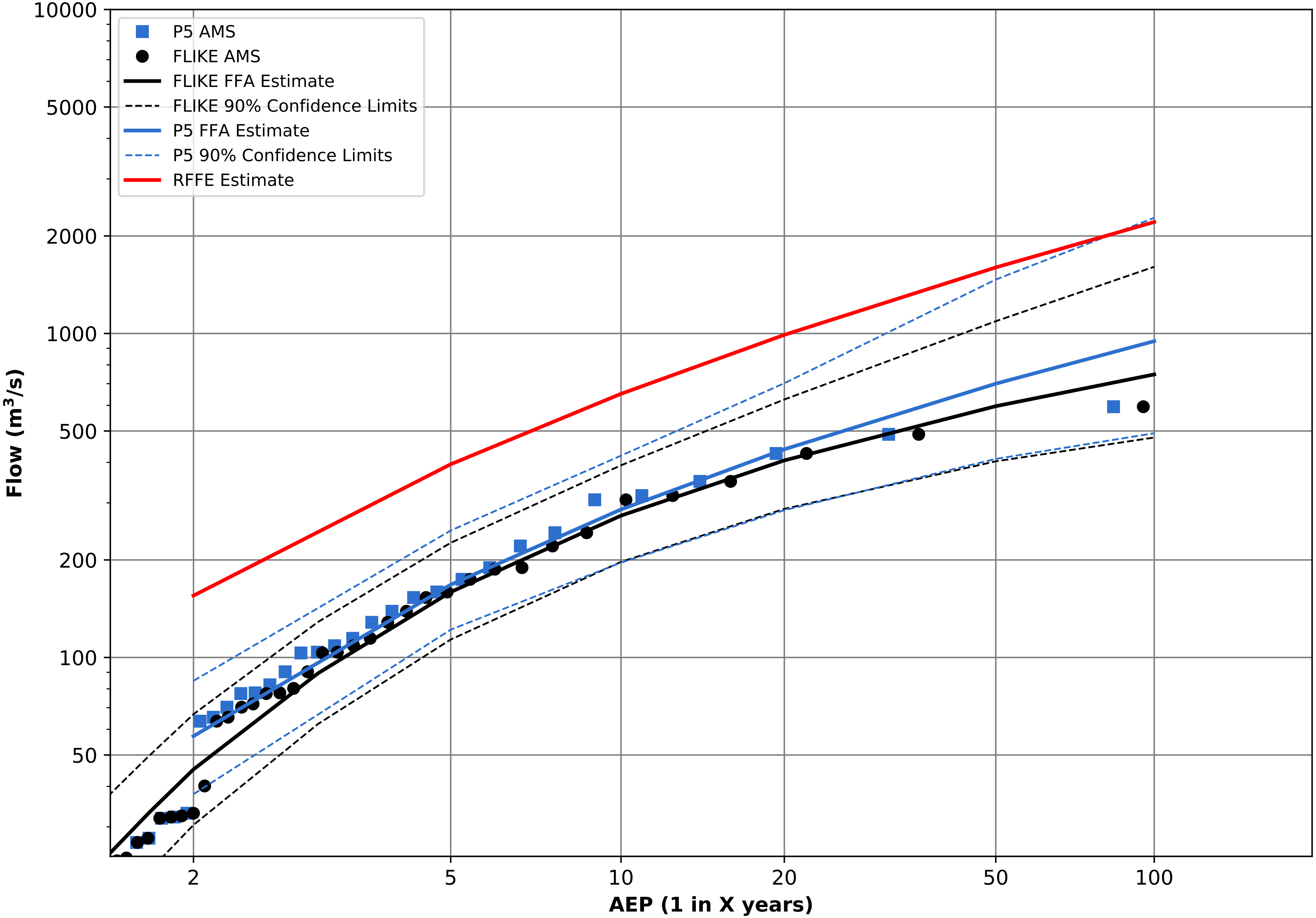


GLEN DAVIS - 212018 [F9]
FFA VARIANTS
APPENDIX A54



LITHGOW - 212011 [F10]
FFA VARIANTS

APPENDIX A55

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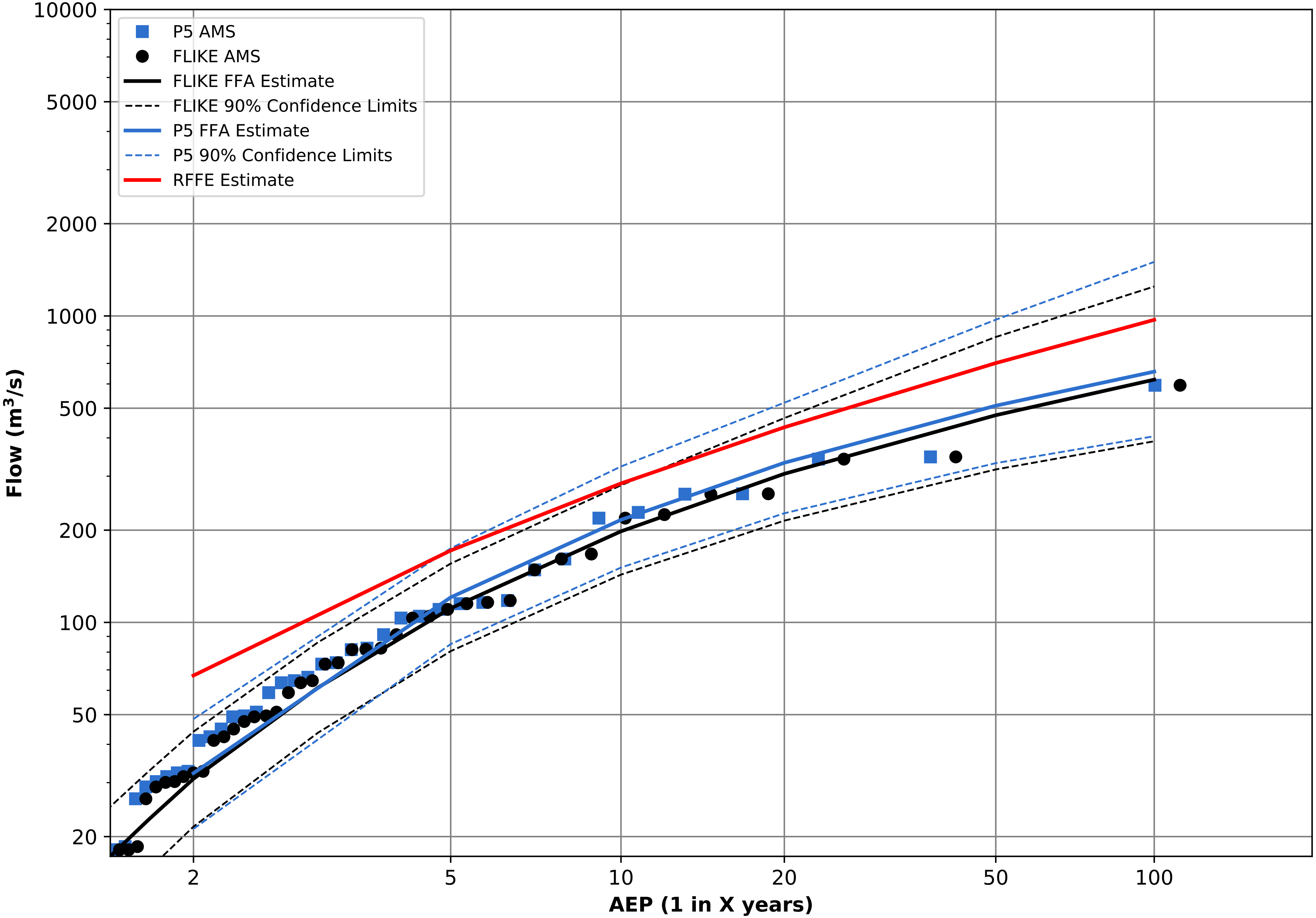

BATHURST RD - 212008 [F11]
FFA VARIANTS
APPENDIX A56

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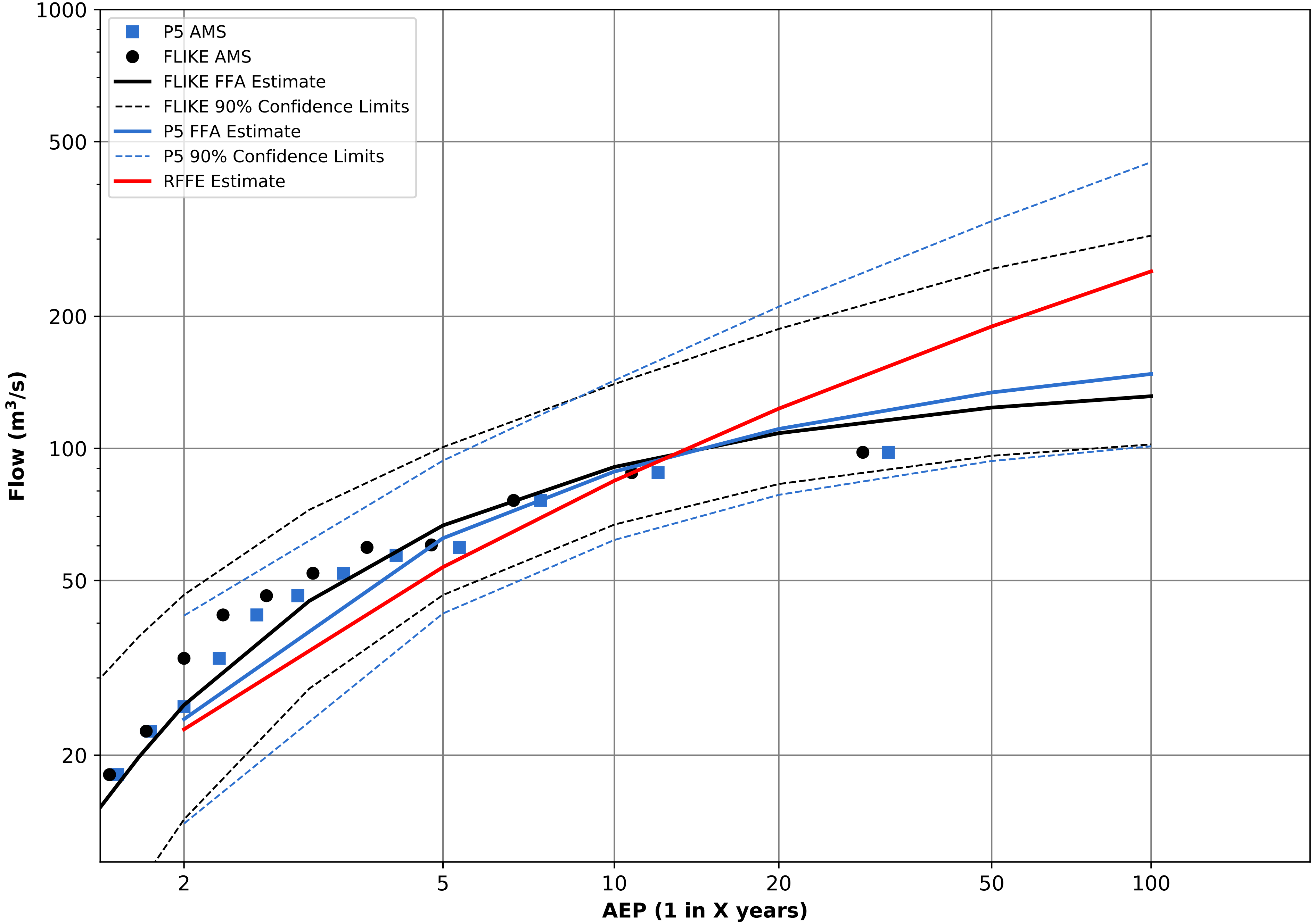

CUDAL NO.2 - 412090 [G1]
FFA VARIANTS
APPENDIX A57

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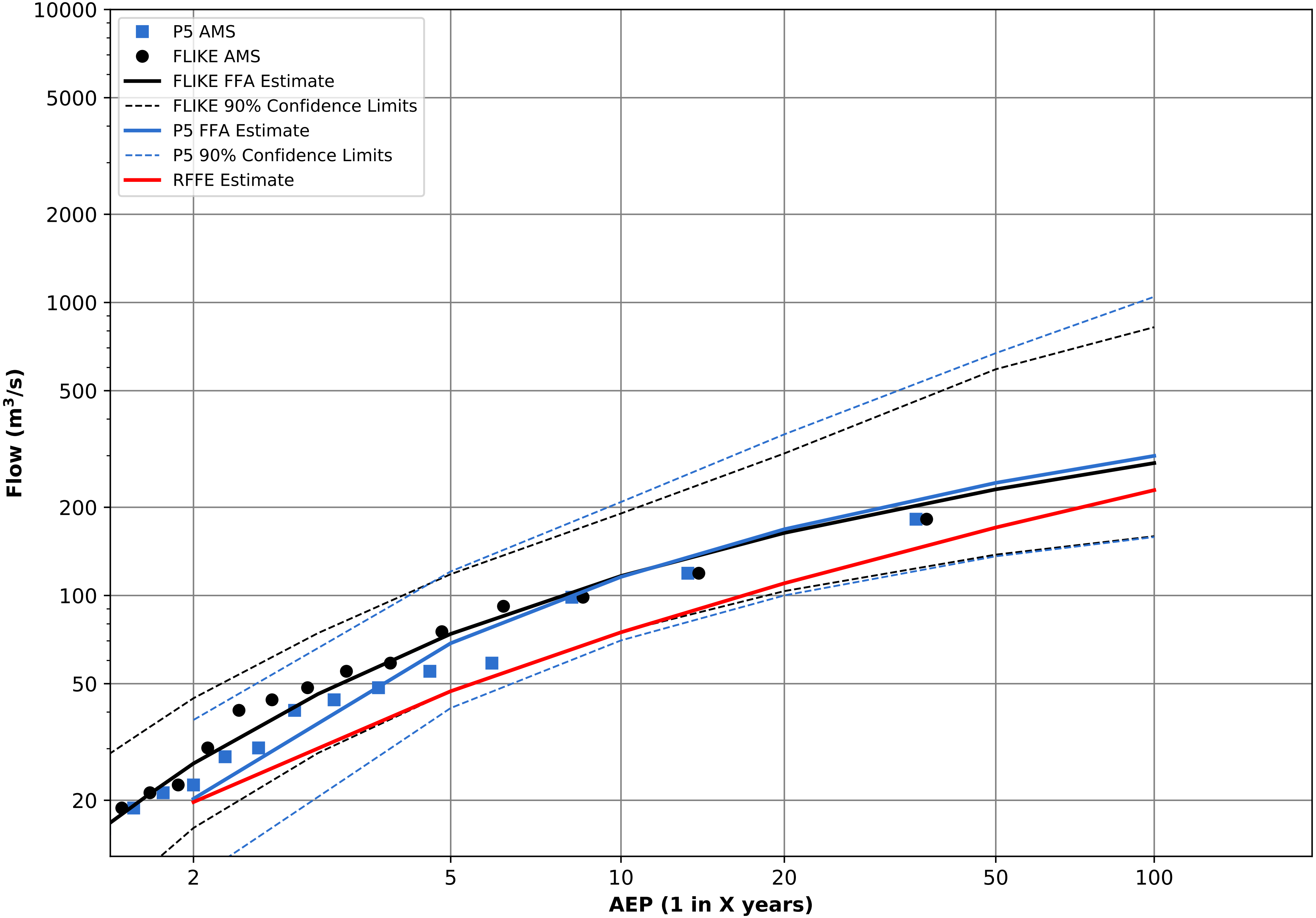
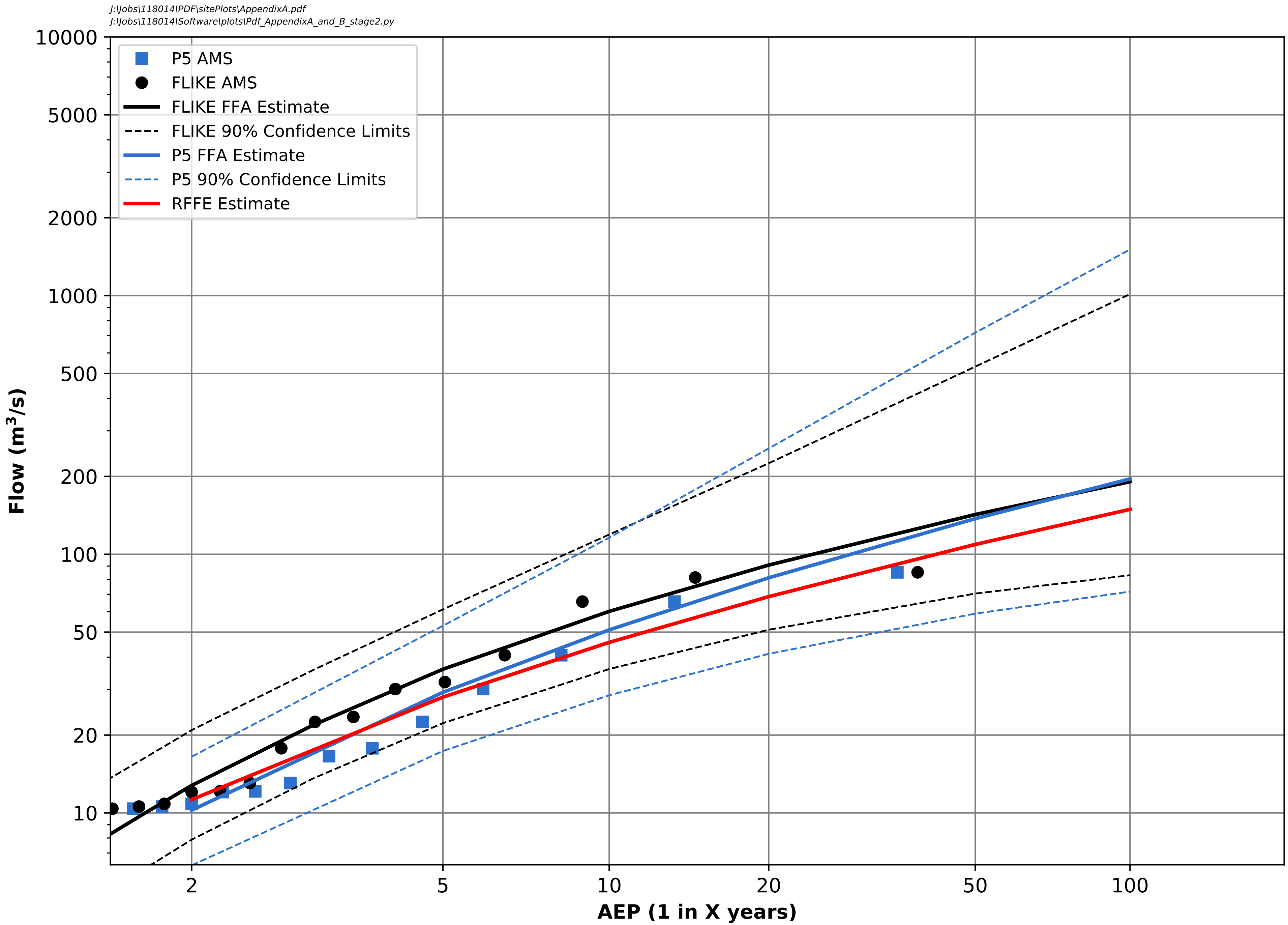


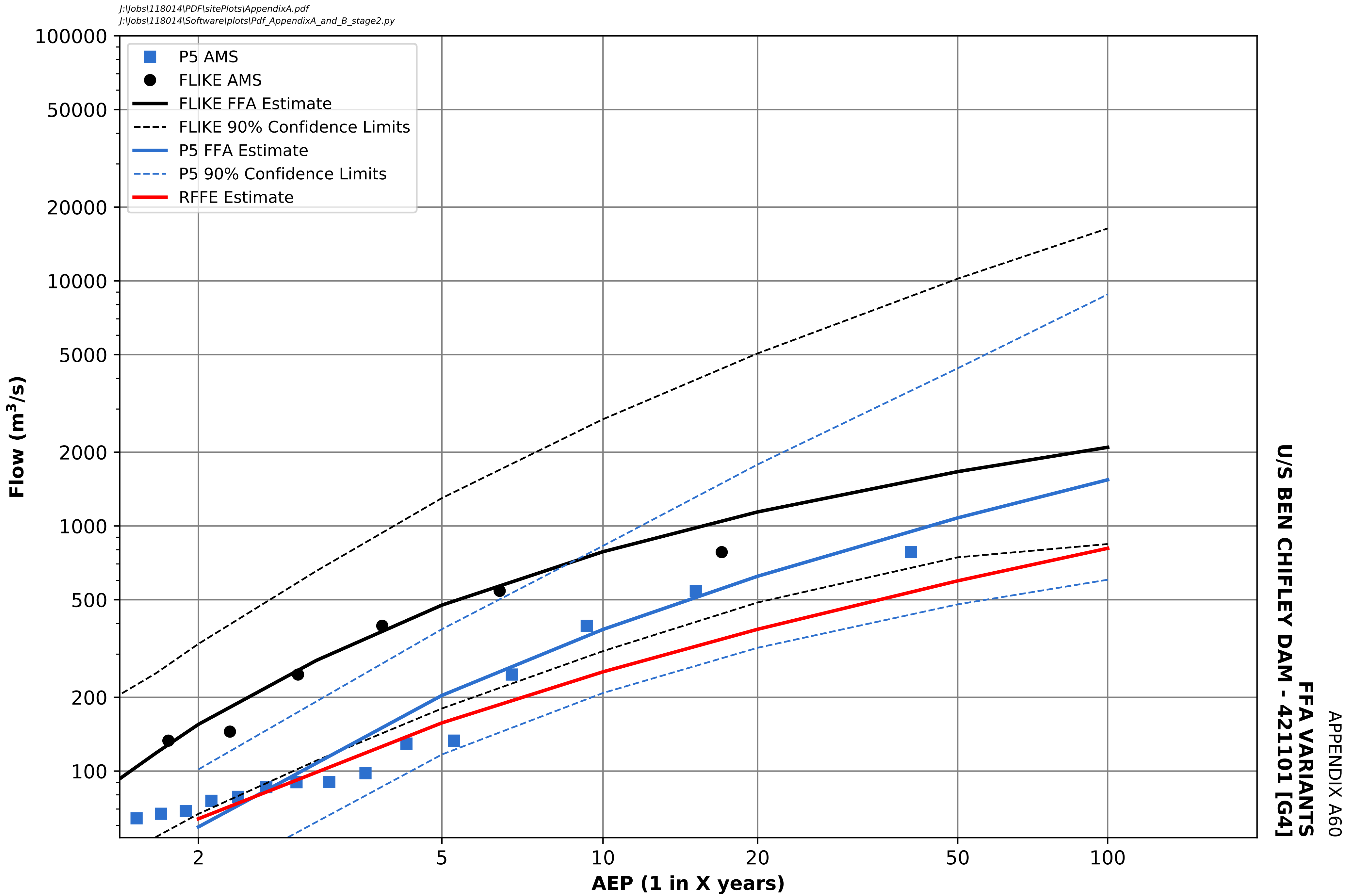
WIAGDON - 421106 [G2]

FFA VARIANTS

APPENDIX A58



STROMLO - 421104 [G3]
FFA VARIANTS
APPENDIX A59


J:\Jobs\118014\PDF\sitePlots\AppendixA.pdf
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
P5 AMS
FLIKE AMS
FLIKE FFA Estimate
FLIKE 90% Confidence Limits
P5 FFA Estimate
P5 90% Confidence Limits
RFFE Estimate
100000
50000
20000
10000
5000
2000
1000
500
200
100
Flow (m³/s)
2
5
10
20
50
100
AEP (1 in X years)
U/S BEN CHIFLEY DAM - 421101 [G4]
FFA VARIANTS
APPENDIX A60

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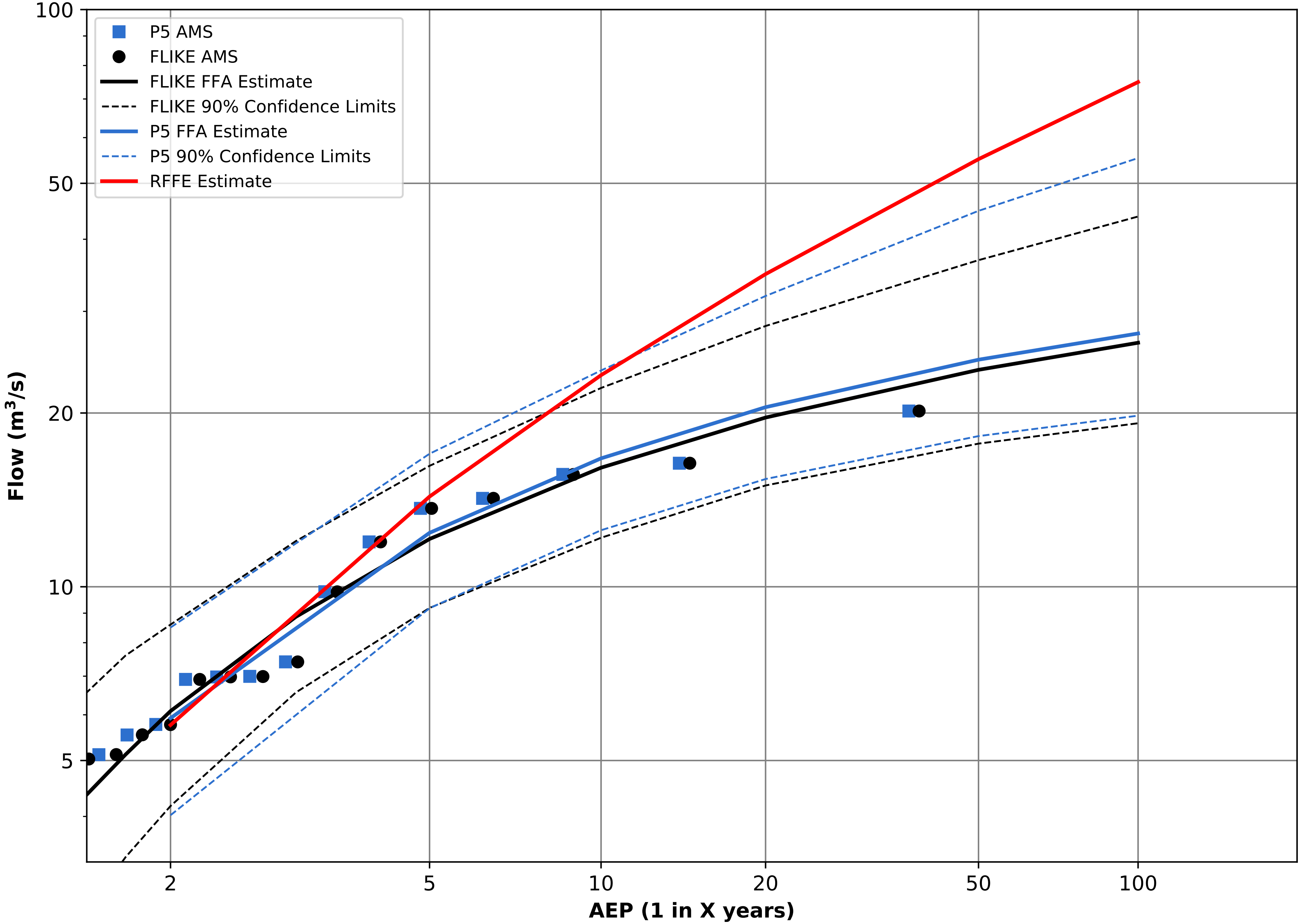

APPENDIX A61
FFA VARIANTS
DAM SITE - 421034 [G5]

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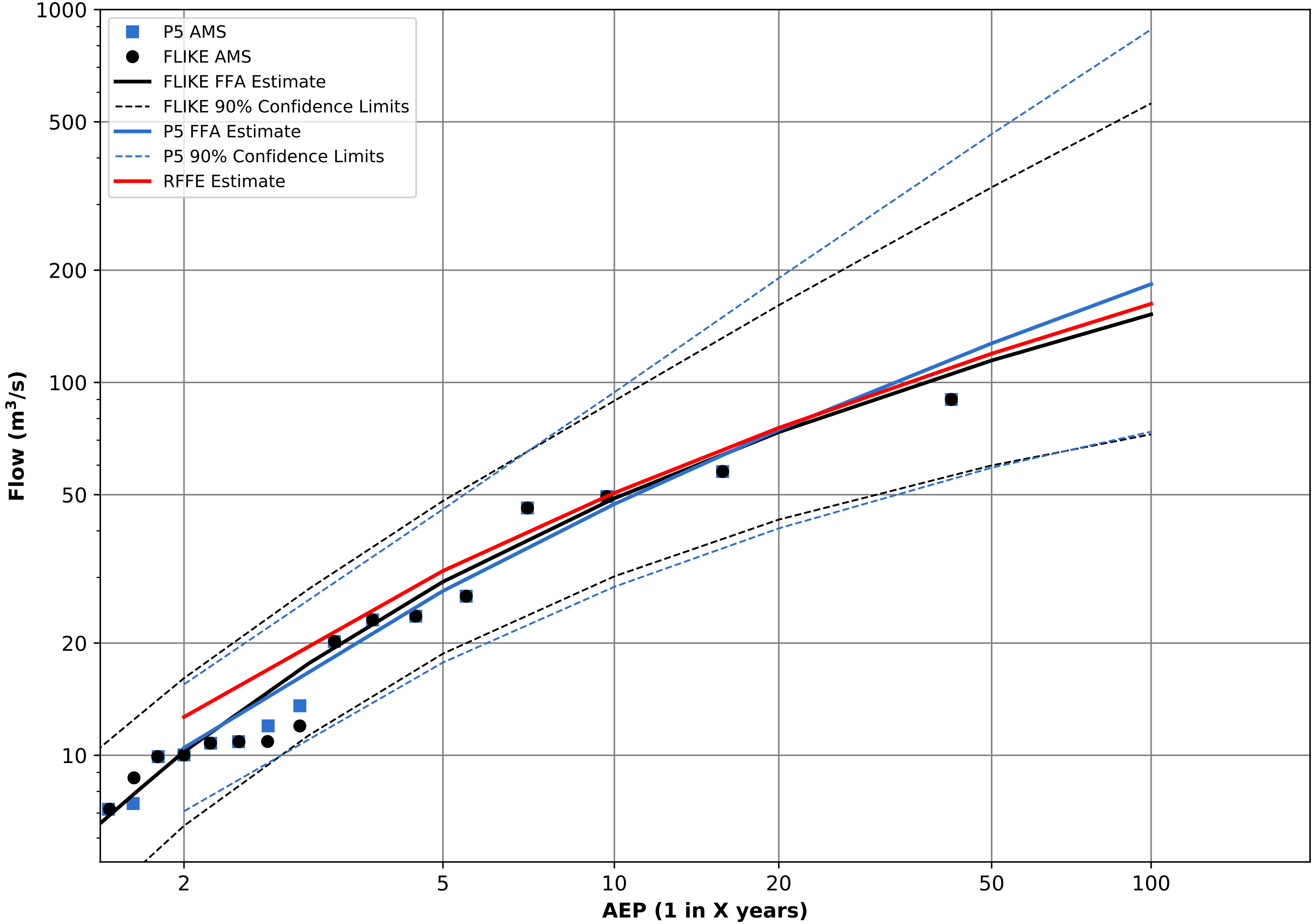
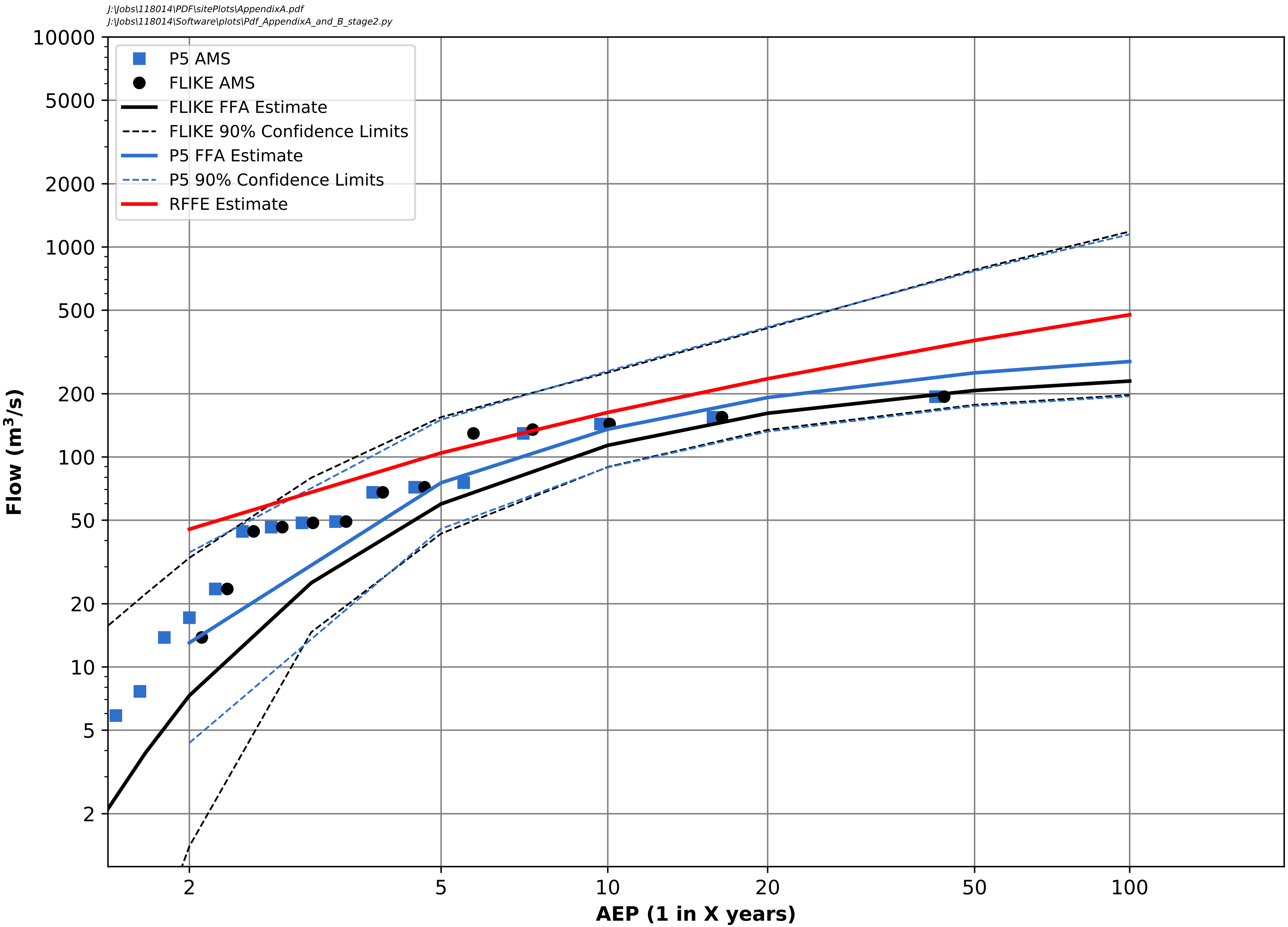


BELOW DAM SITE - 421036 [G6]
FFA VARIANTS
APPENDIX A62



SAXA CROSSING - 421068 [G7]

FFA VARIANTS

APPENDIX A63

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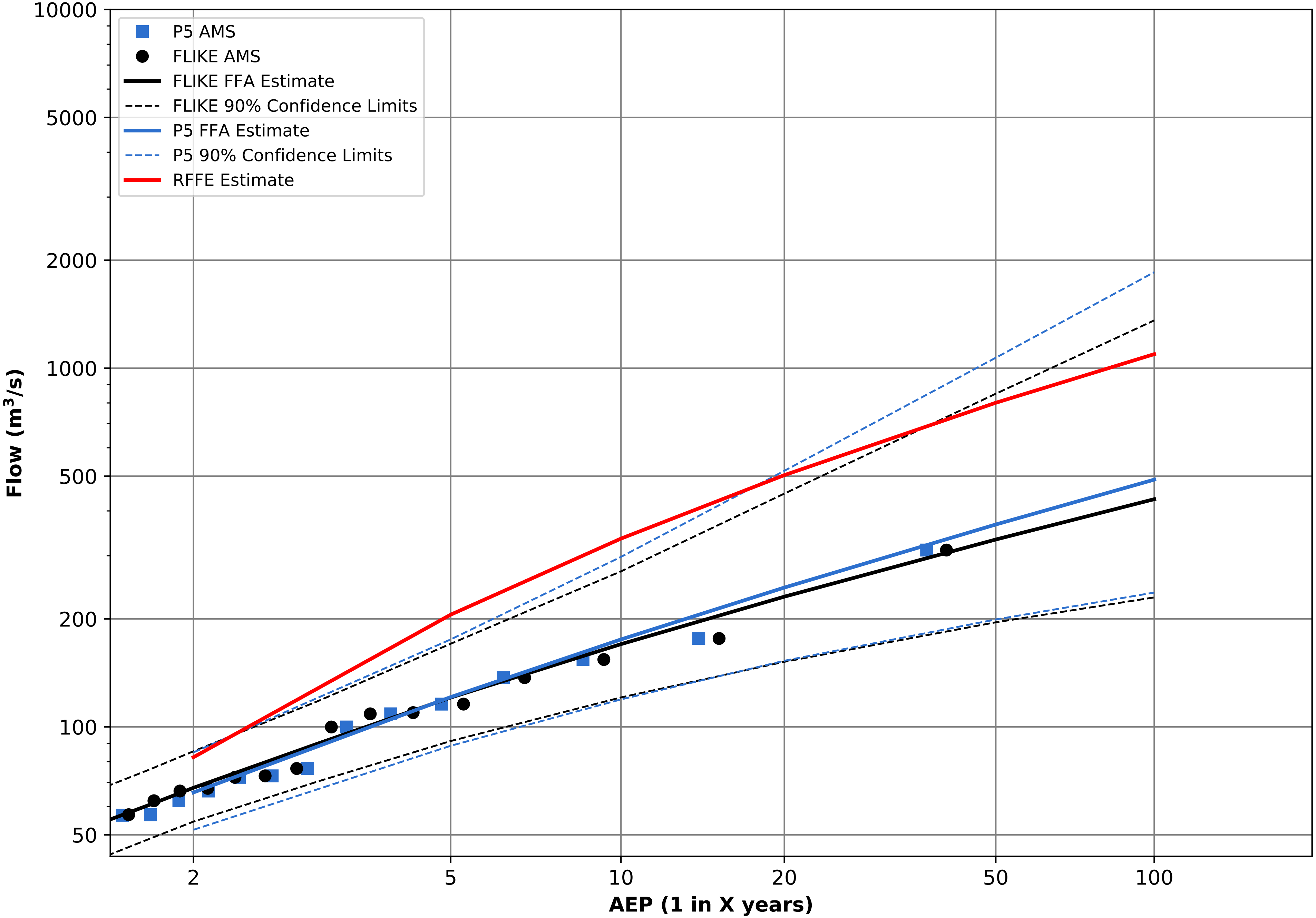
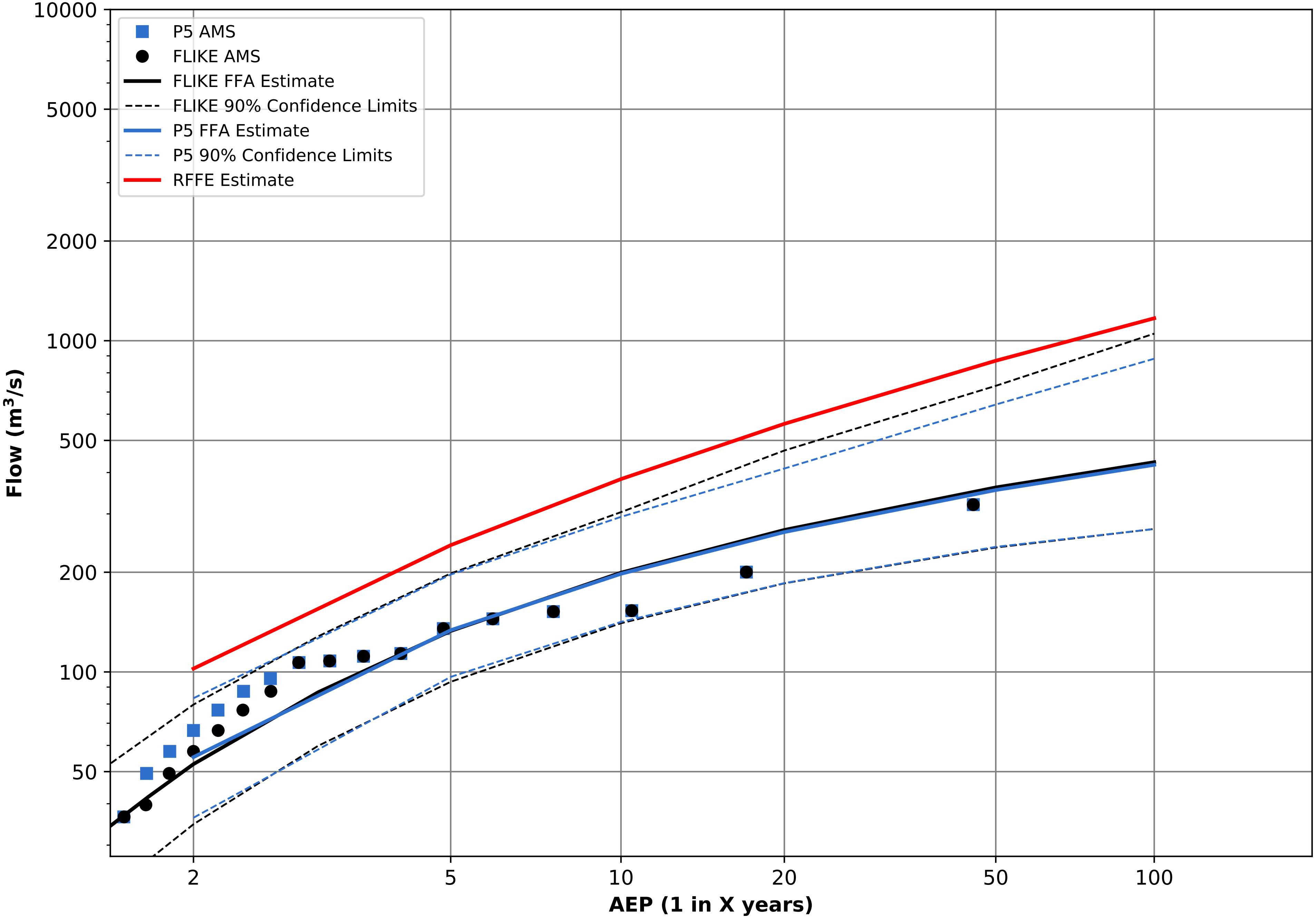


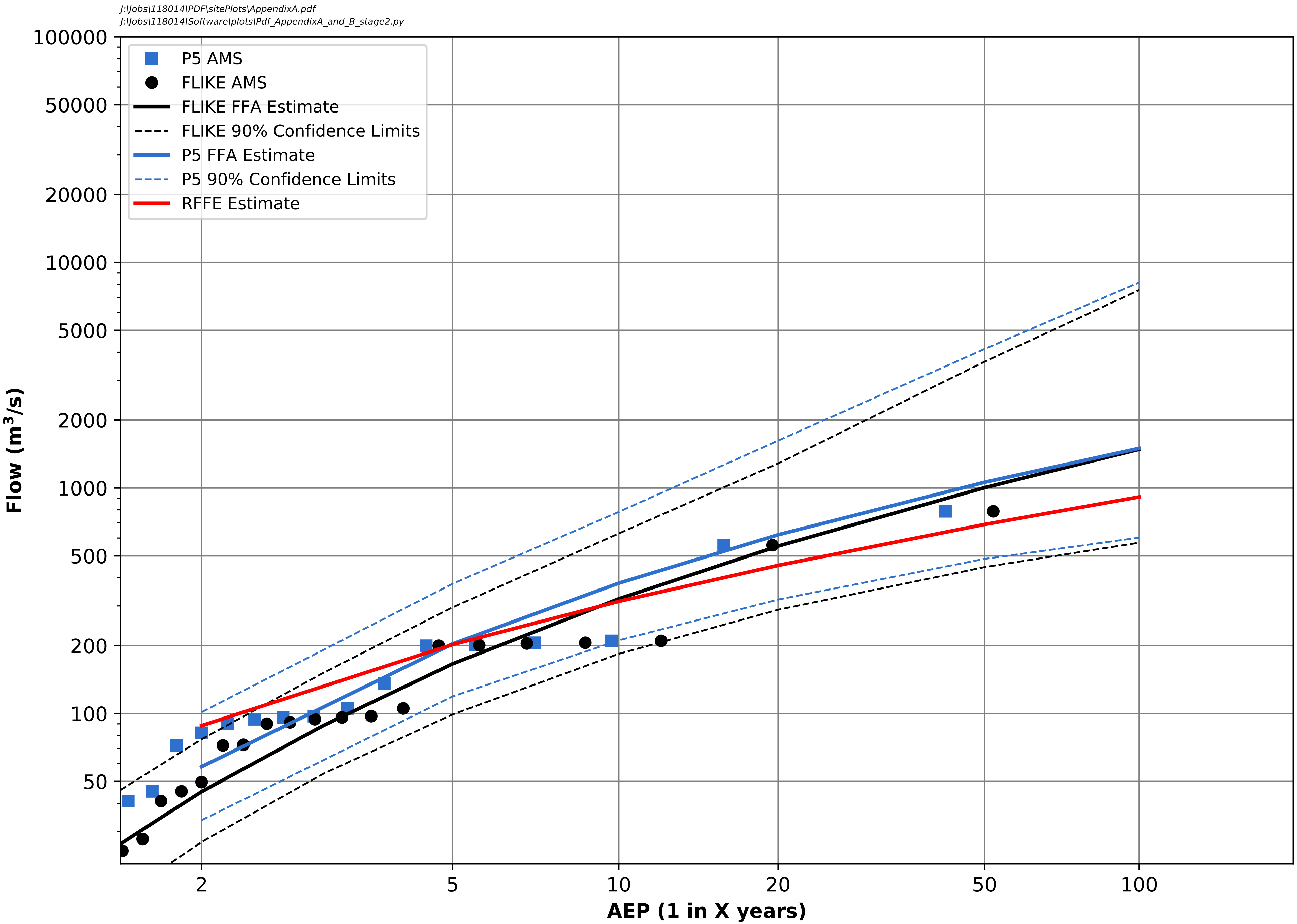
APPENDIX A64

FFA VARIANTS

HILL END - 421066 [G8]



KENNYS CK RD - 412096 [G9]
FFA VARIANTS



OBLEY NO.2 - 421048 [G10]
FFA VARIANTS

APPENDIX A66

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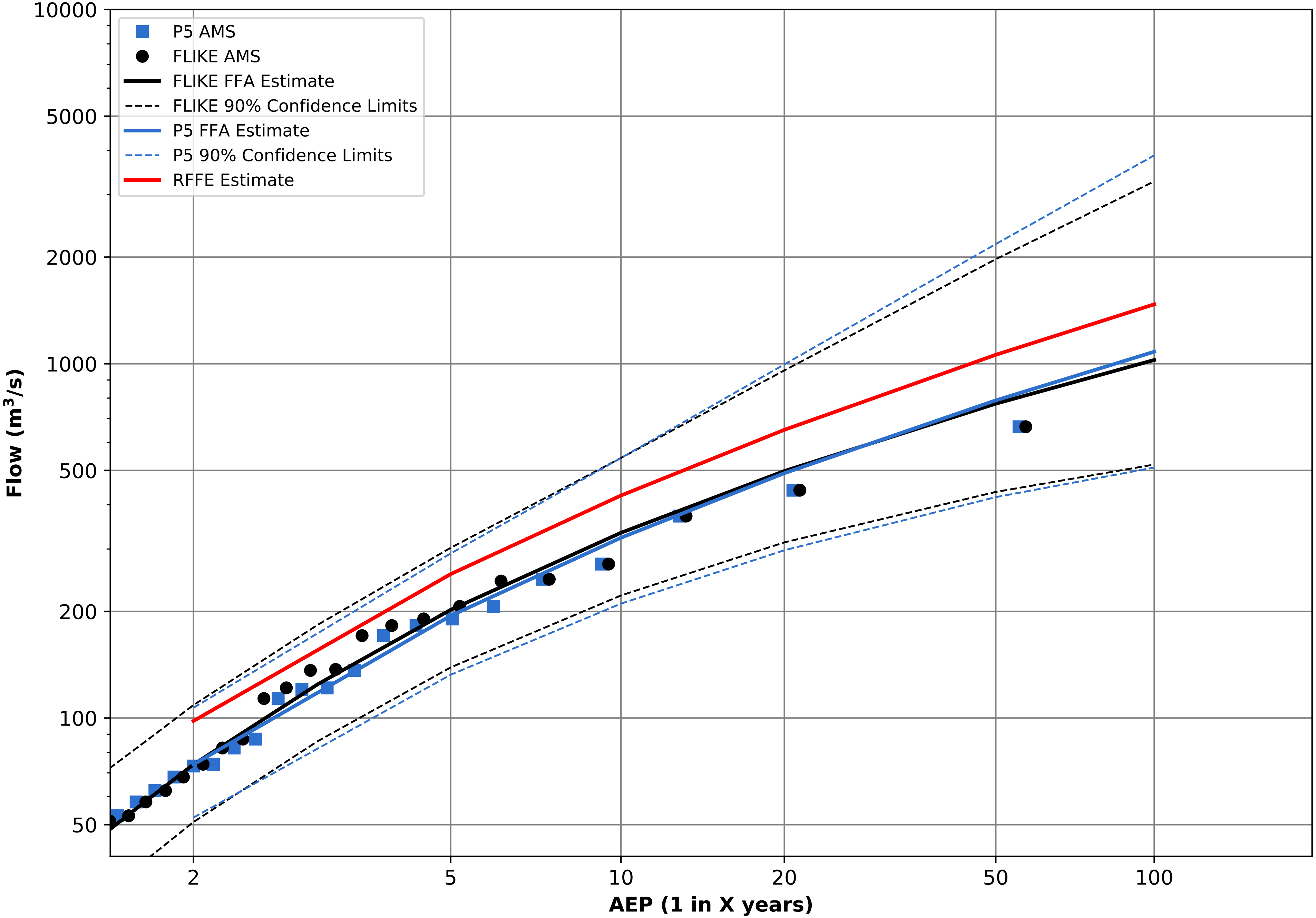

FFA VARIANTS

TUENA - 412083 [G11]

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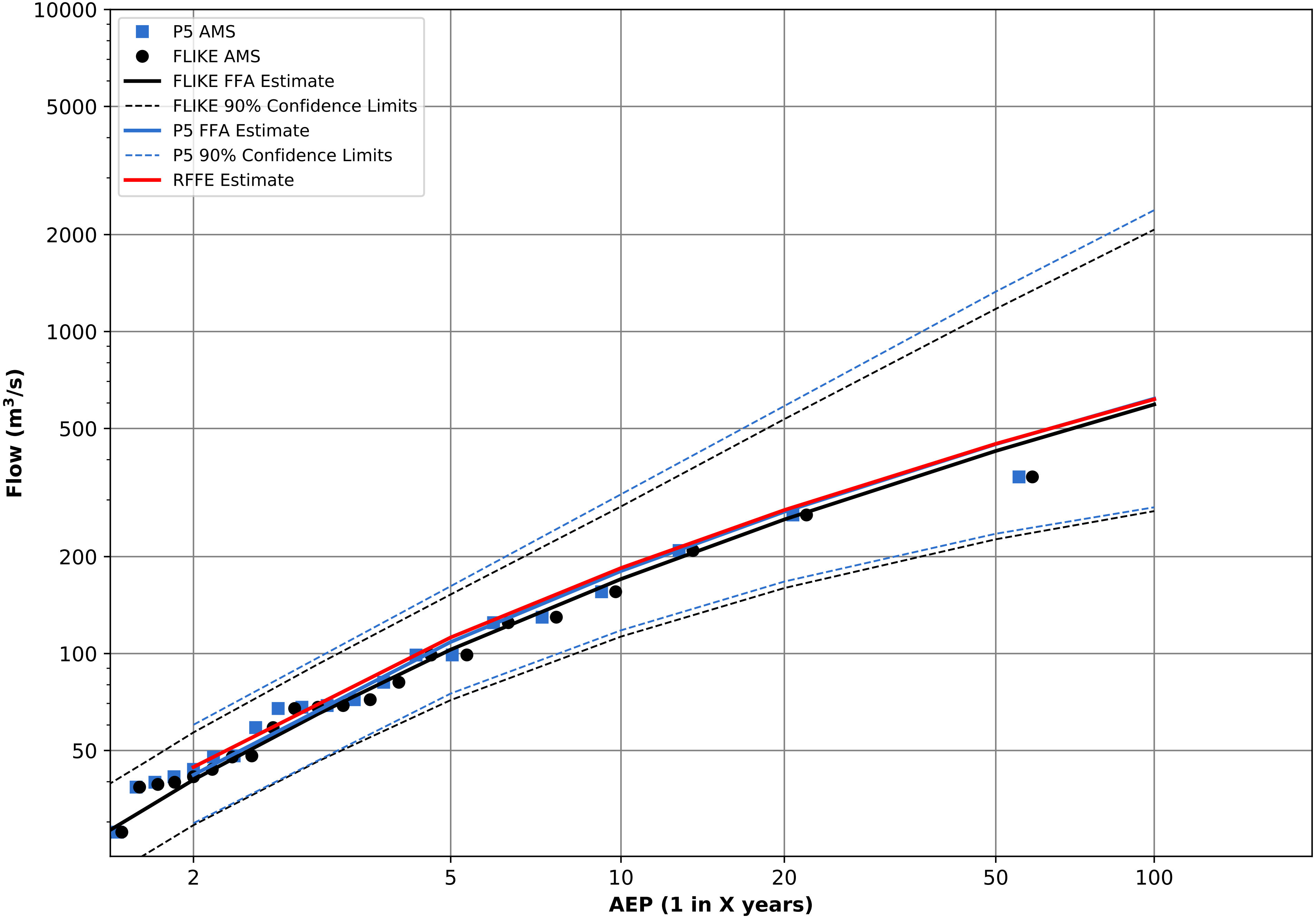

APPENDIX A68

FFA VARIANTS

NEAR NEVILLE - 412081 [G12]

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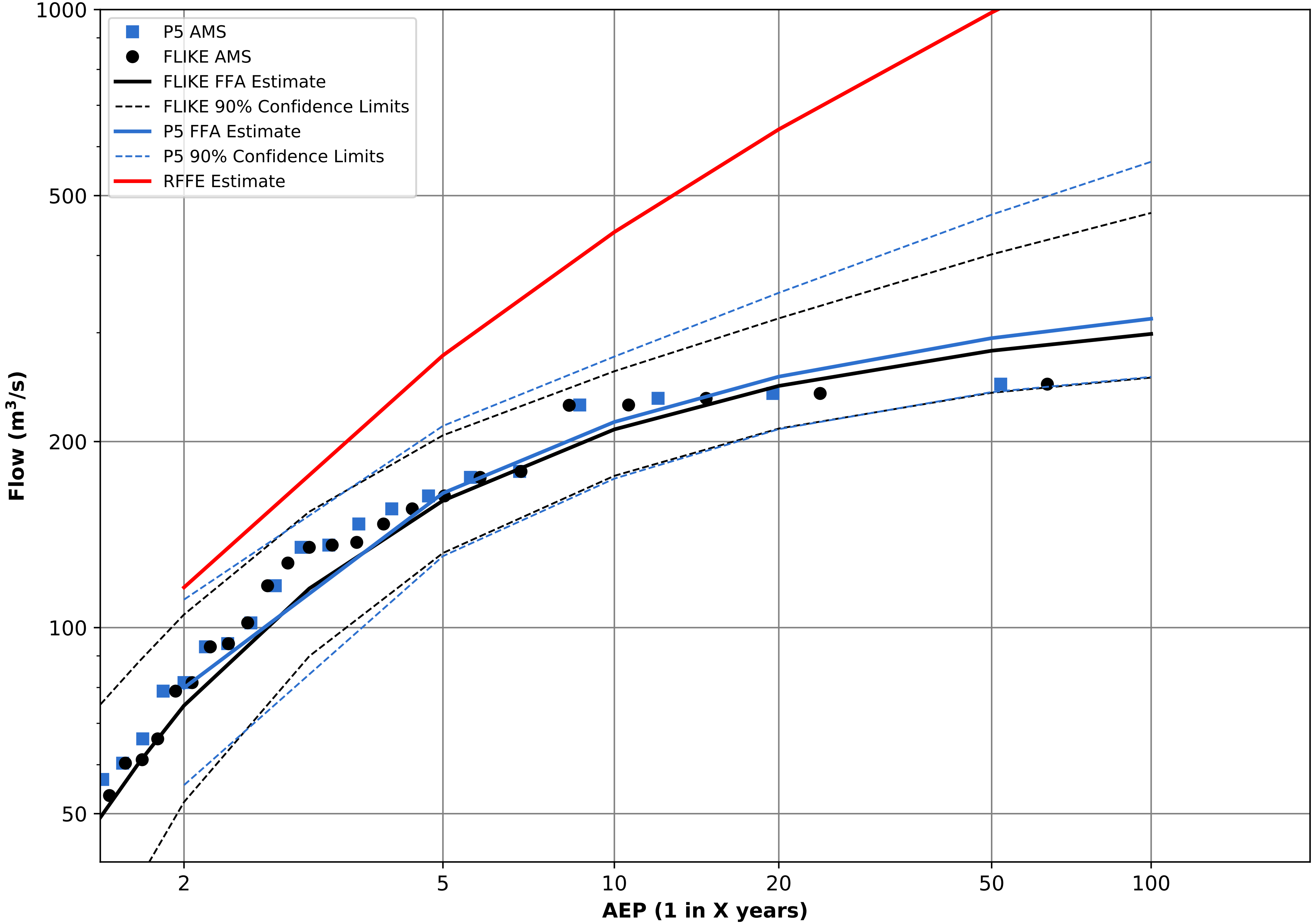

RAWSONVILLE - 421055 [G13]
FFA VARIANTS

APPENDIX A69

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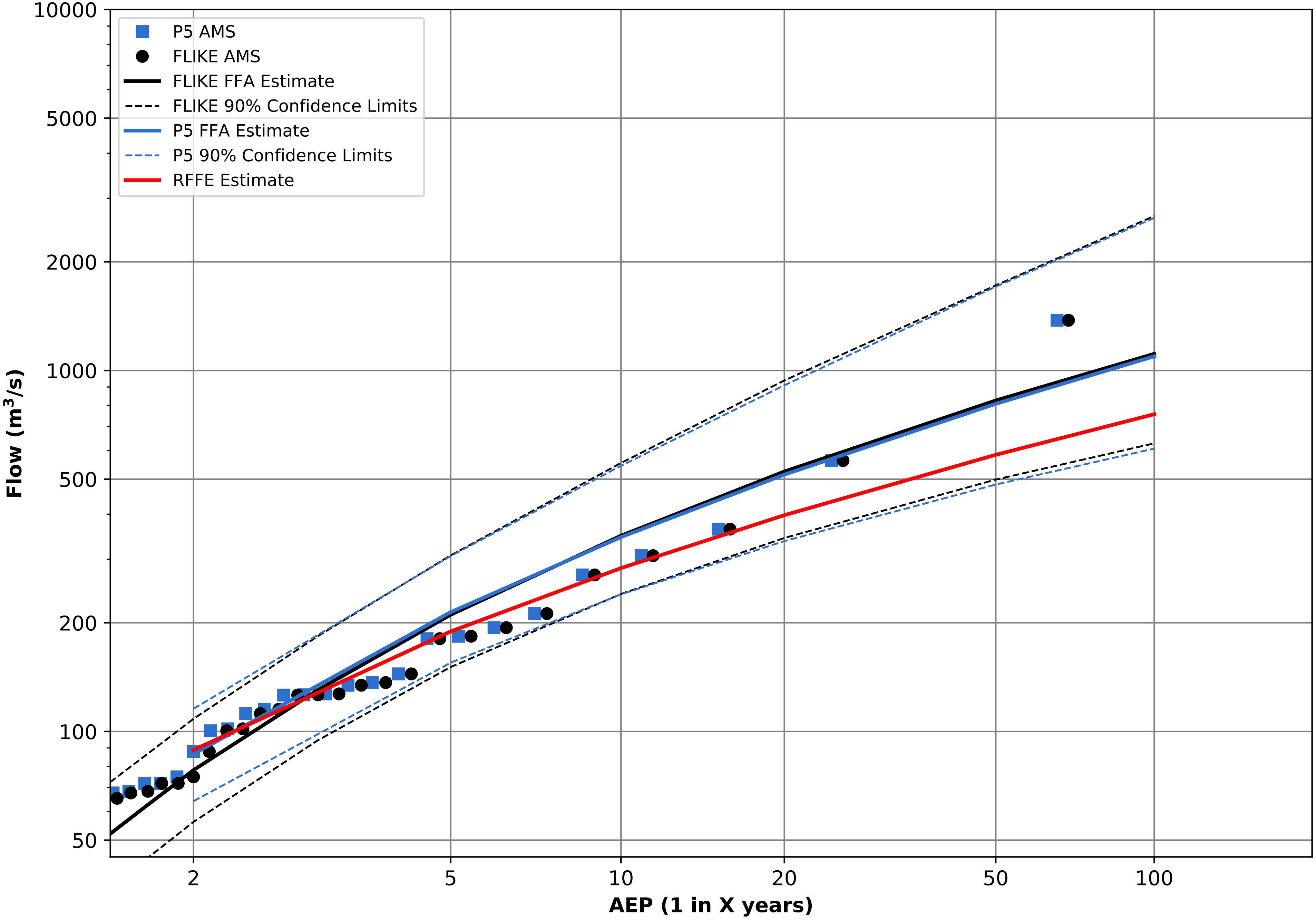

APPENDIX A70

FFA VARIANTS

GUNNING - 412063 [G14]

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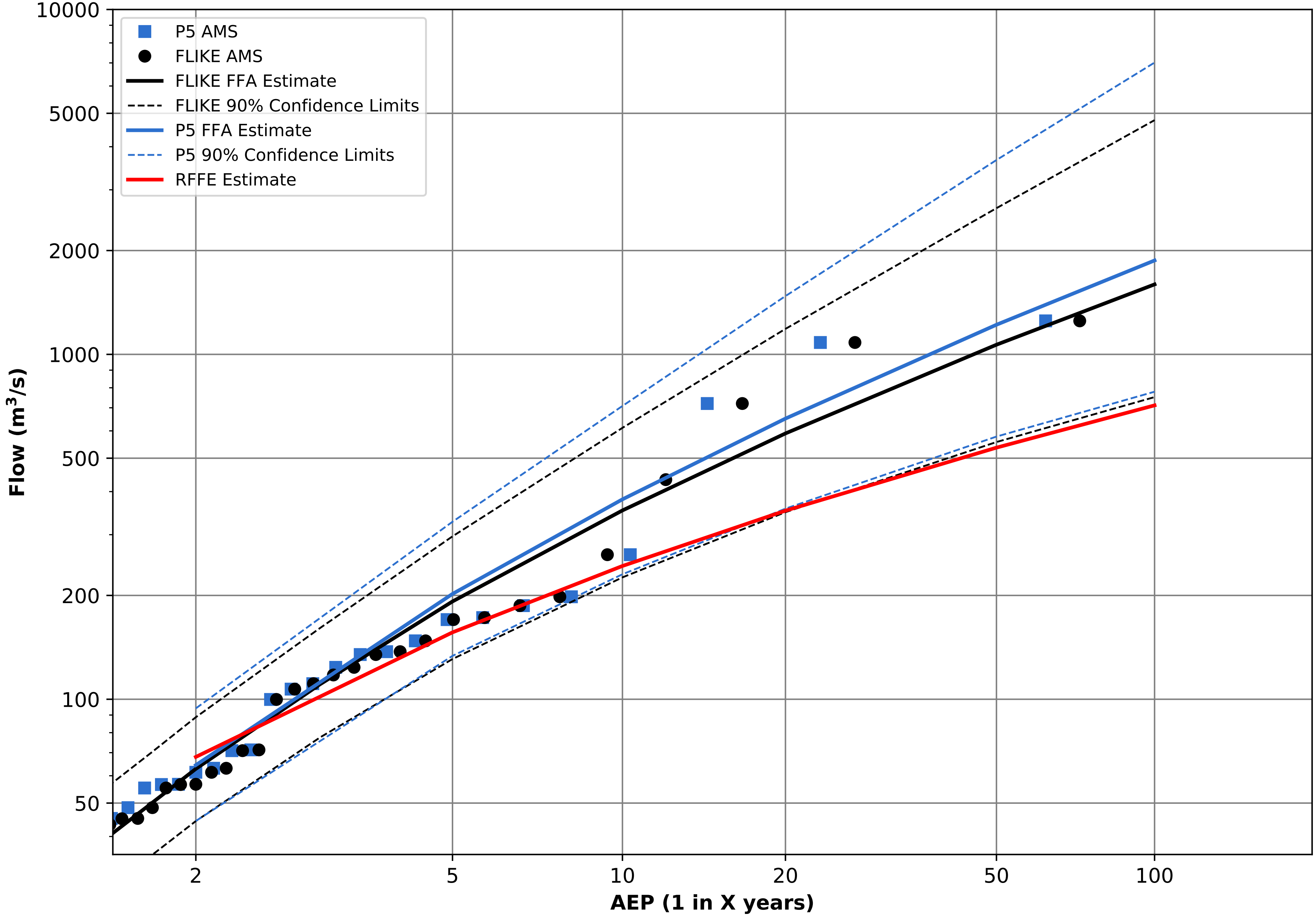

MOLONG - 421050 [G15]
FFA VARIANTS
APPENDIX A71

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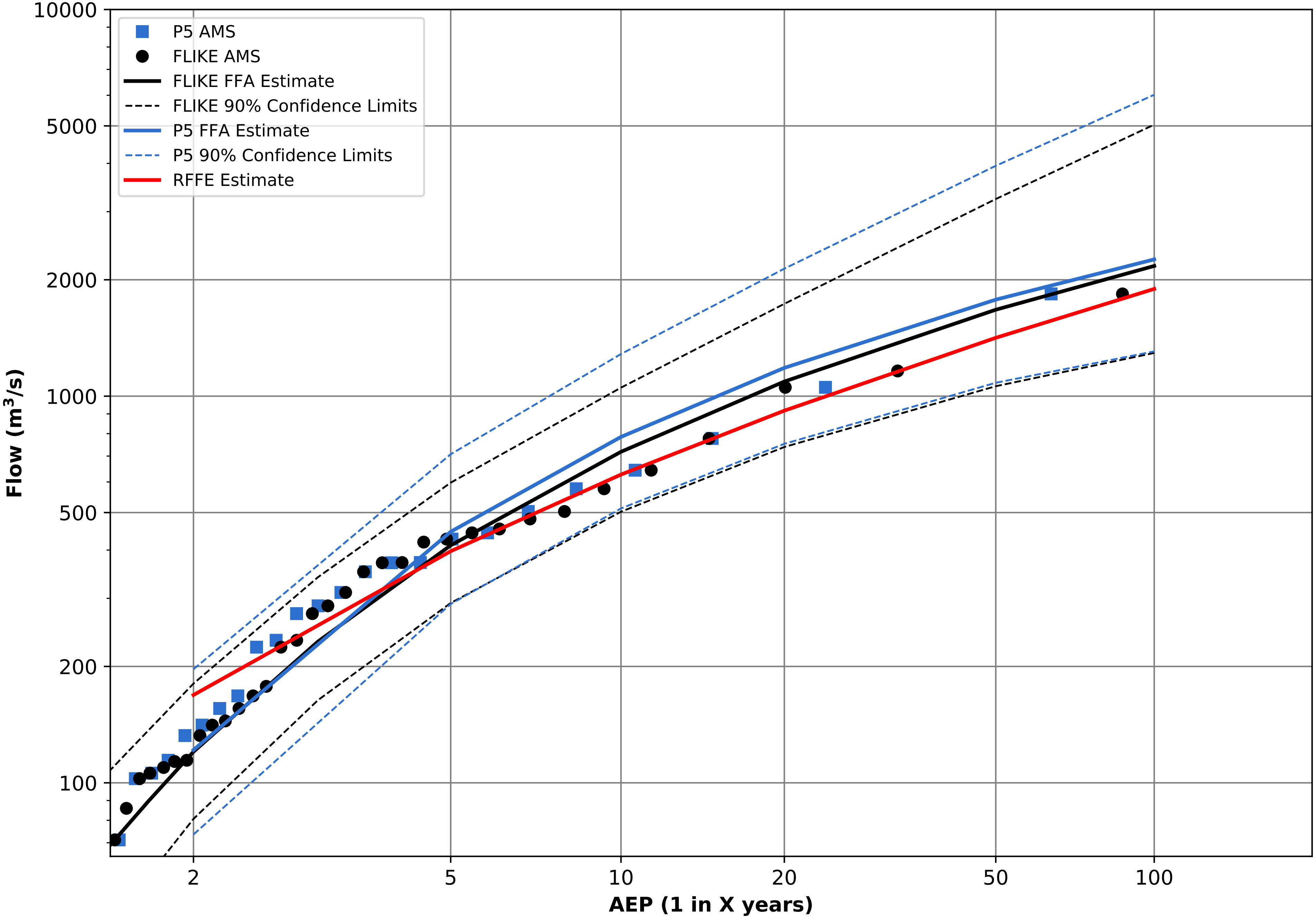
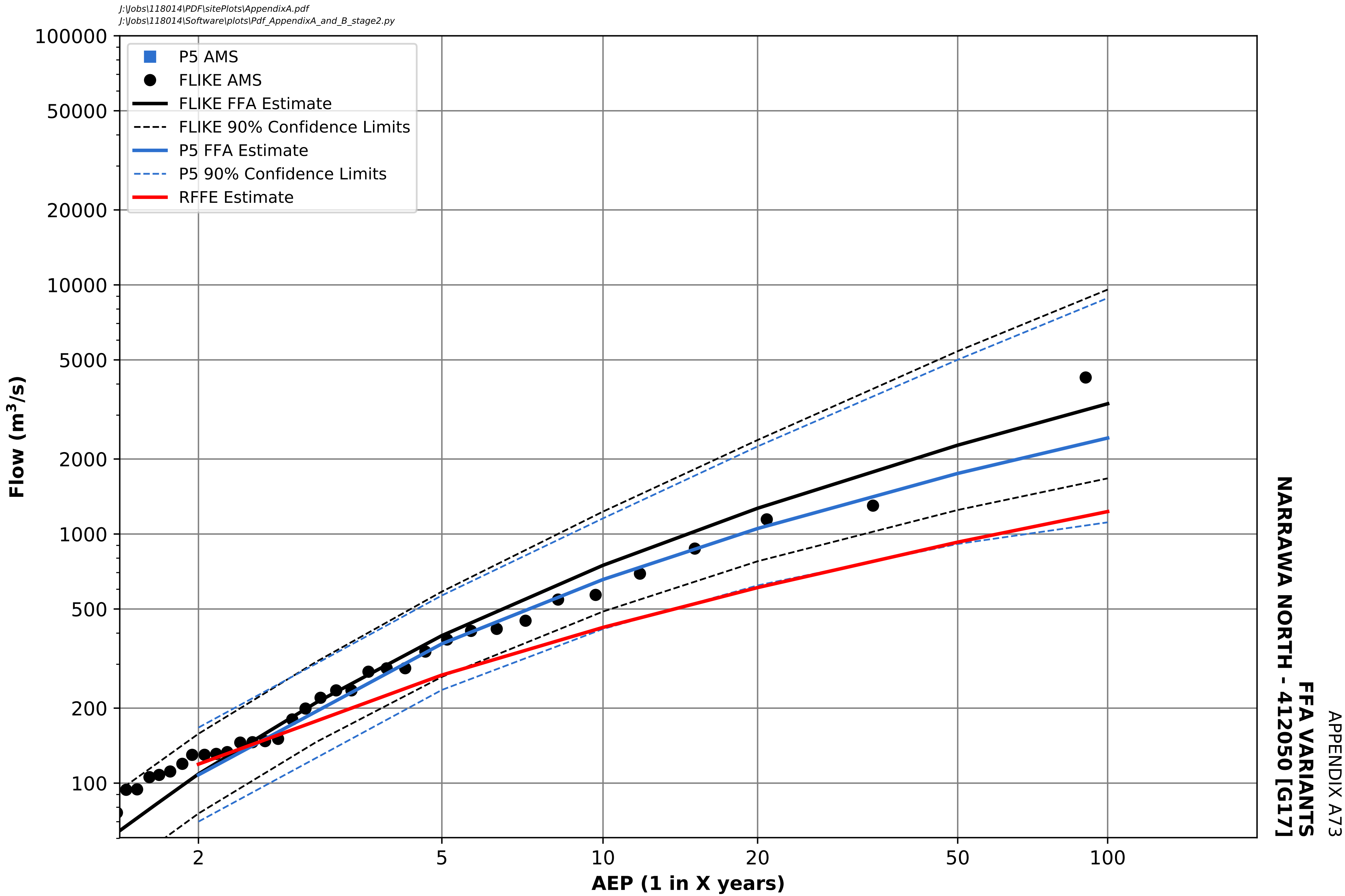


SOFALA - 421026 [G16]
FFA VARIANTS
APPENDIX A72



J:\Jobs\118014\PDF\sitePlots\AppendixA.pdf
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P5 AMS
FLIKE AMS
FLIKE FFA Estimate
FLIKE 90% Confidence Limits
P5 FFA Estimate
P5 90% Confidence Limits
RFFE Estimate
100000
50000
20000
10000
5000
2000
1000
500
200
100
Flow (m³/s)
2
5
10
20
50
100
AEP (1 in X years)
NARRAWA NORTH - 412050 [G17]
FFA VARIANTS
APPENDIX A73

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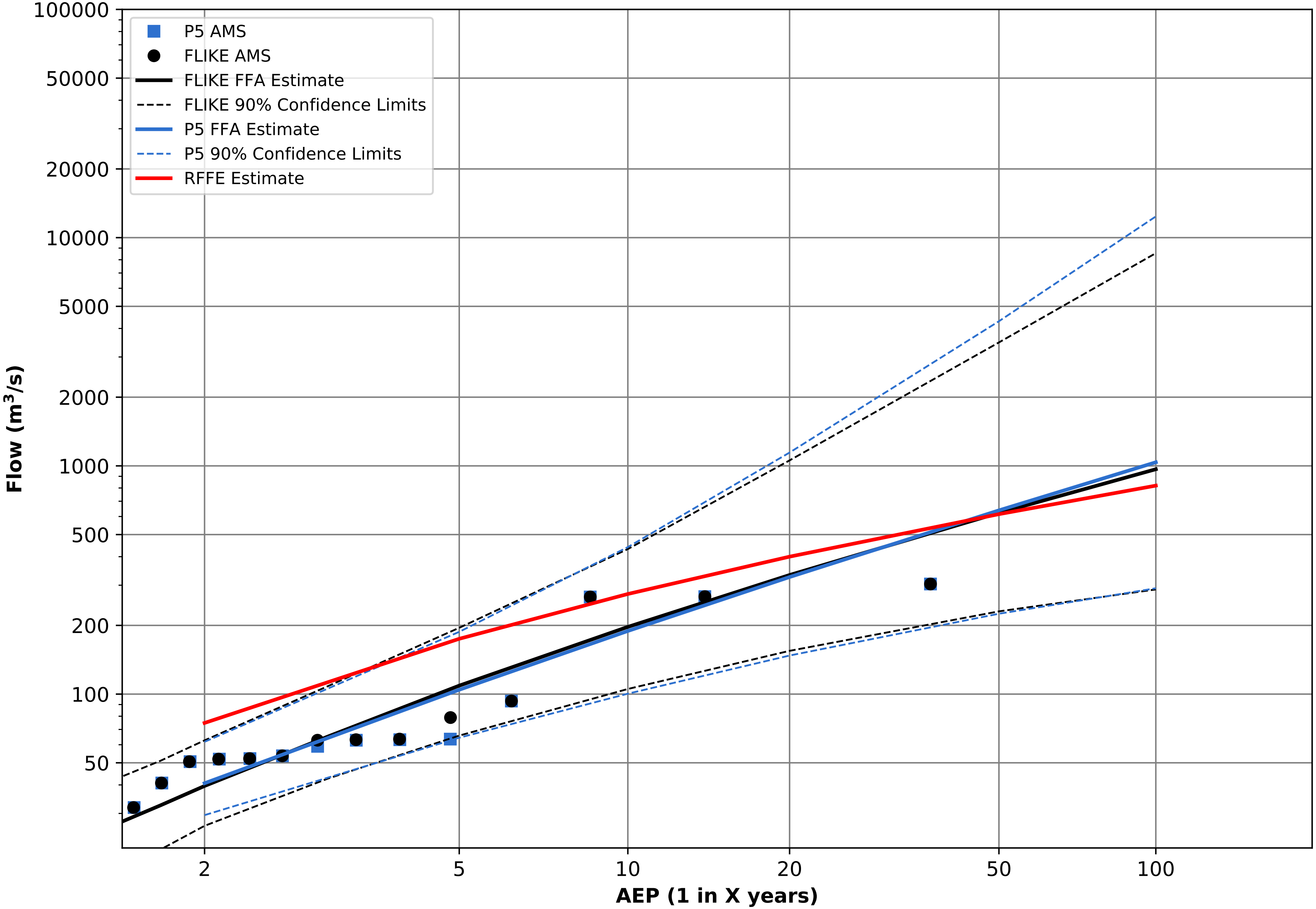

NEILREX - 420012 [G18]
FFA VARIANTS
APPENDIX A74

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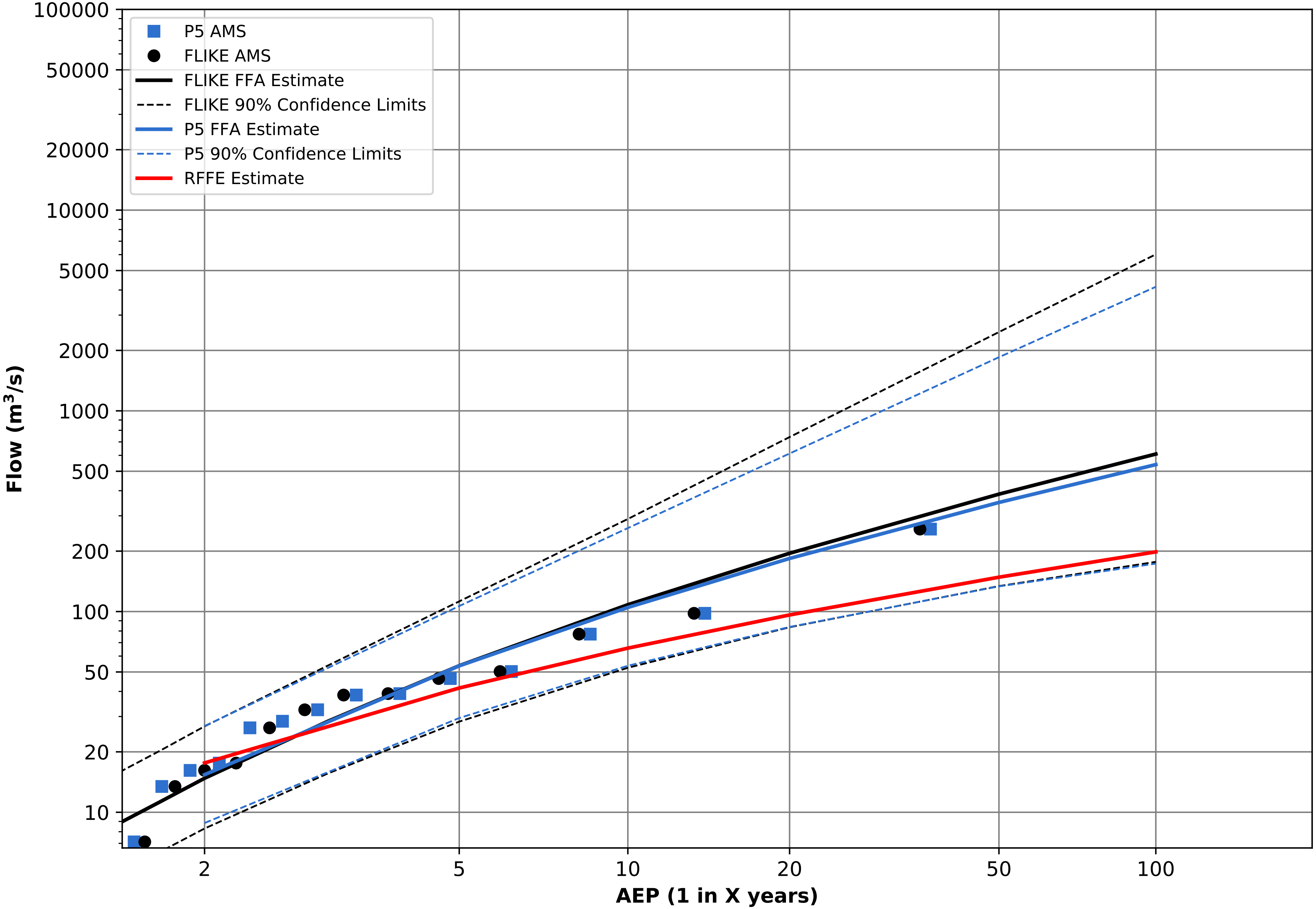

BEARBUNG - 420010 [G19]

FFA VARIANTS

APPENDIX A75

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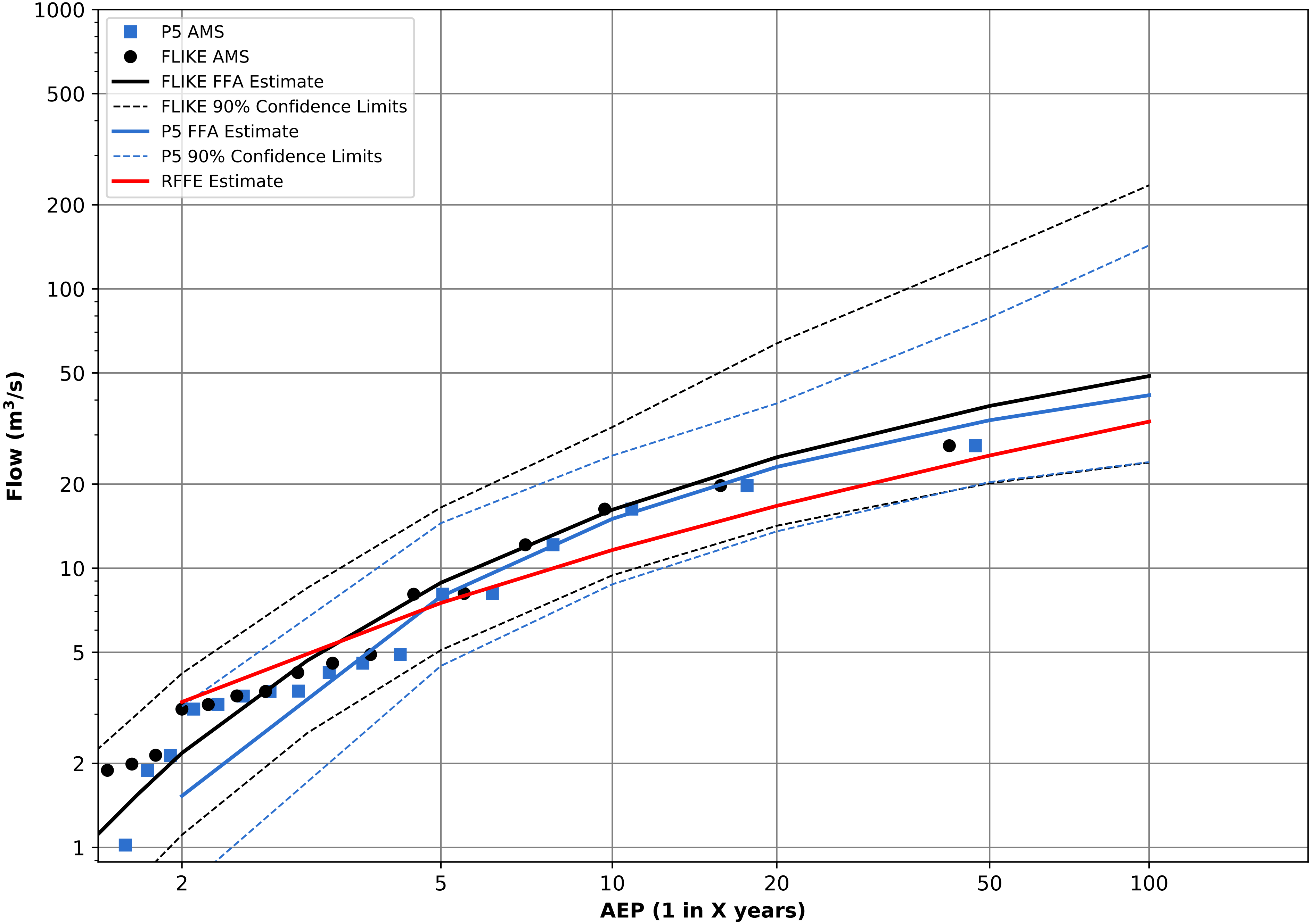

POKOLBIN SITE 4 - 210069 [H1]
FFA VARIANTS

APPENDIX A76

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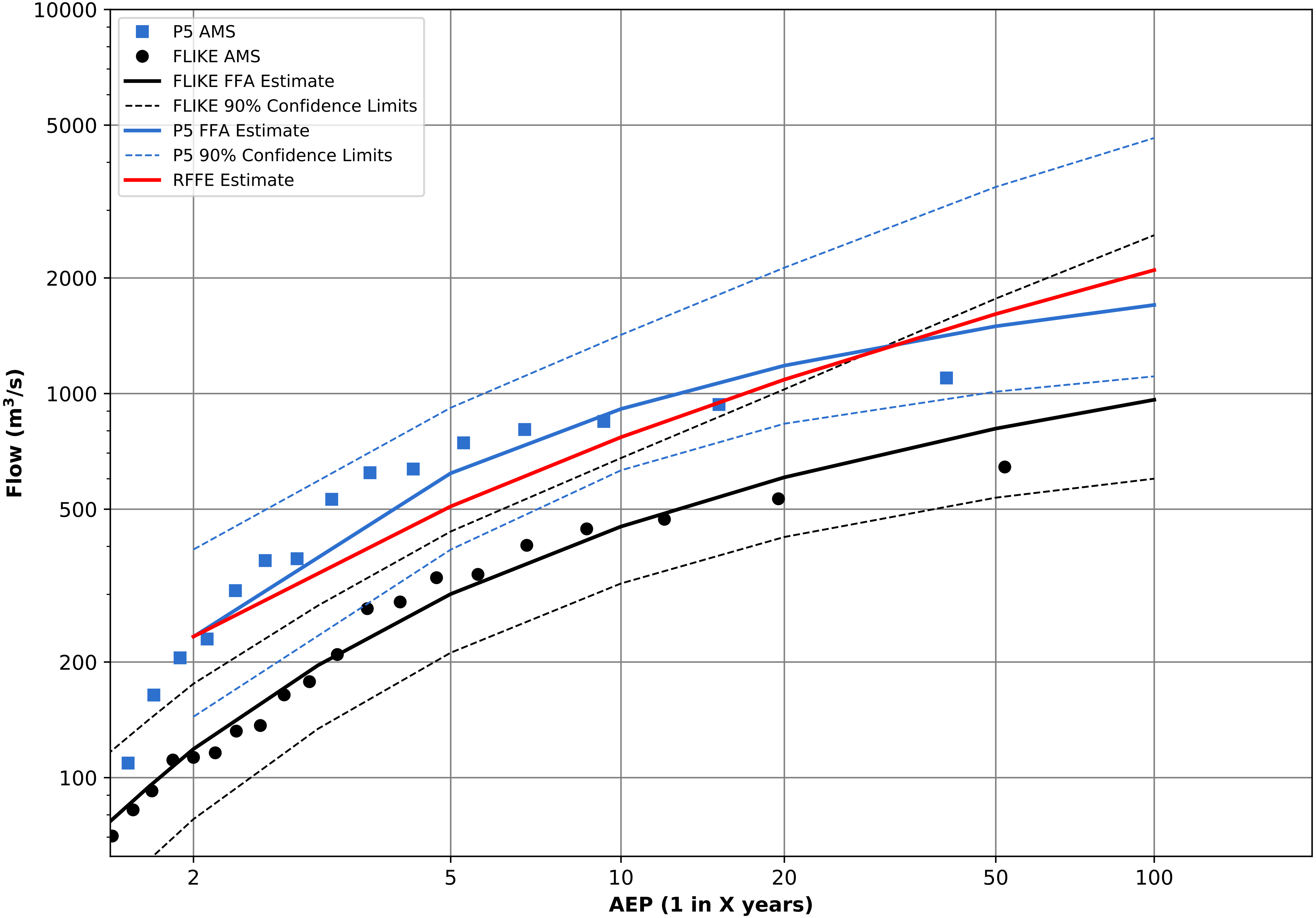

MEASURING WEIR - 208027 [H2]
FFA VARIANTS

APPENDIX A77

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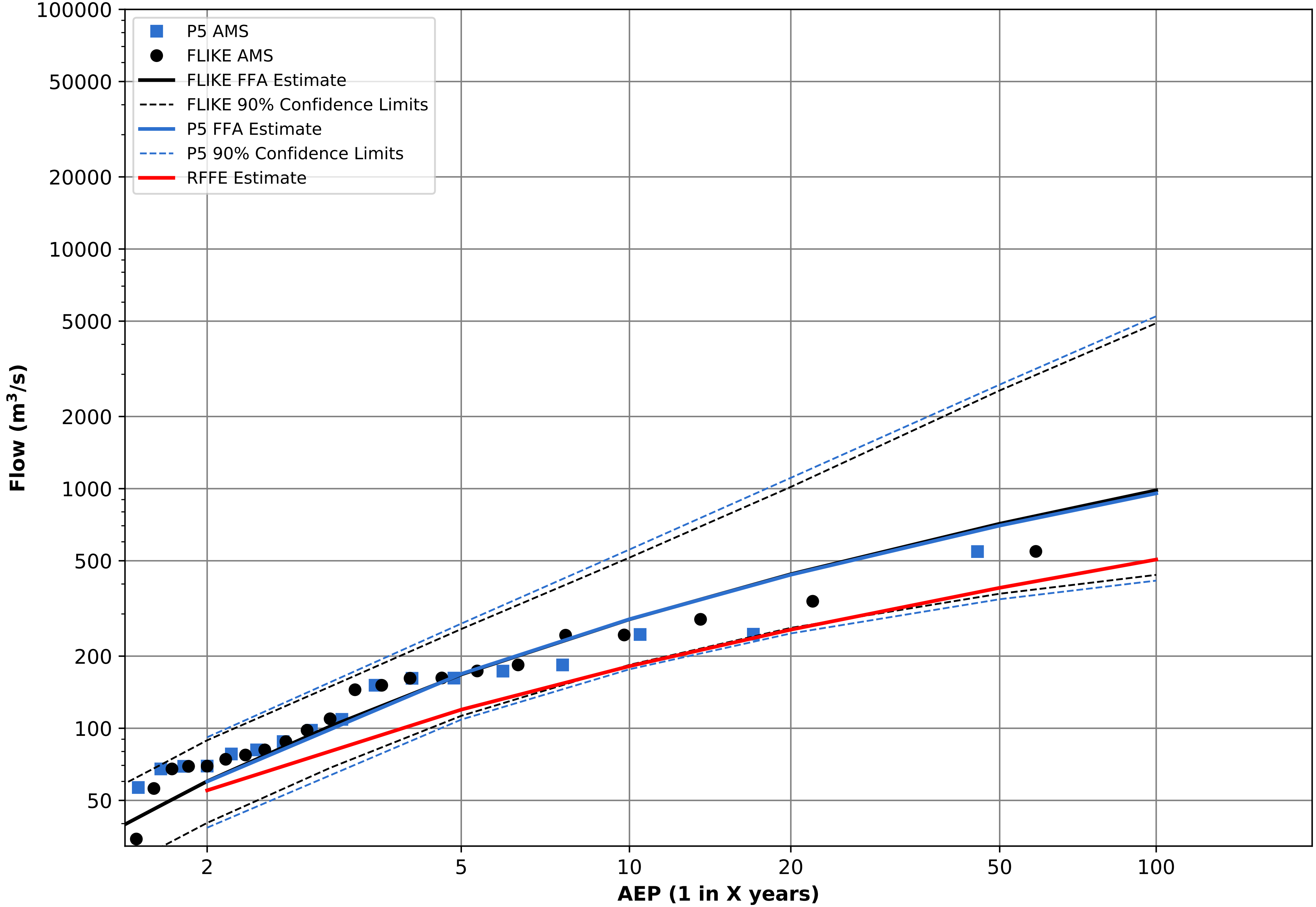

FORBESDALE (CAUSEWAY) - 208026 [H3]

FFA VARIANTS

APPENDIX A78

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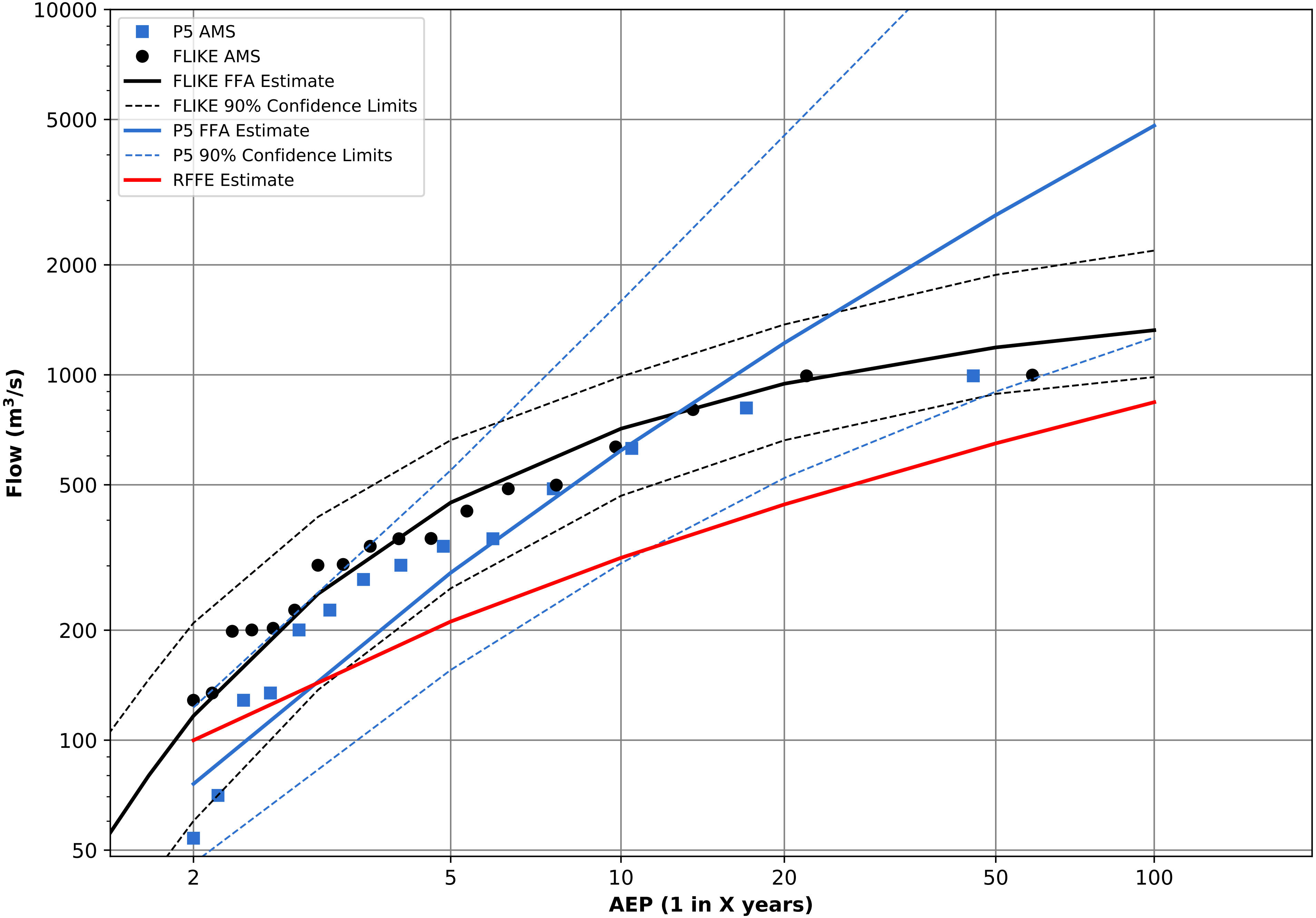

MOUNT SEAVIEW - 207015 [H4]
FFA VARIANTS
APPENDIX A79

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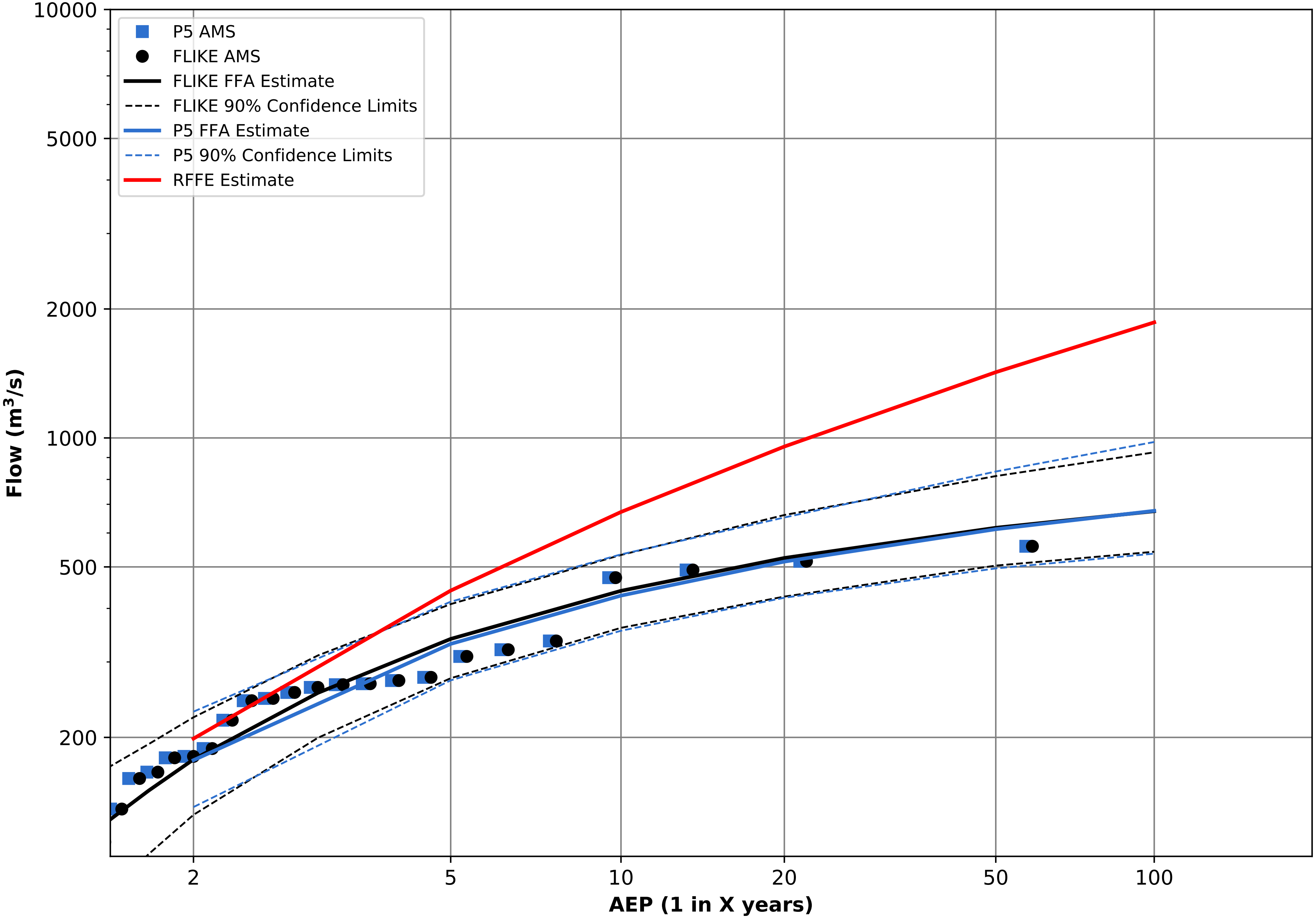
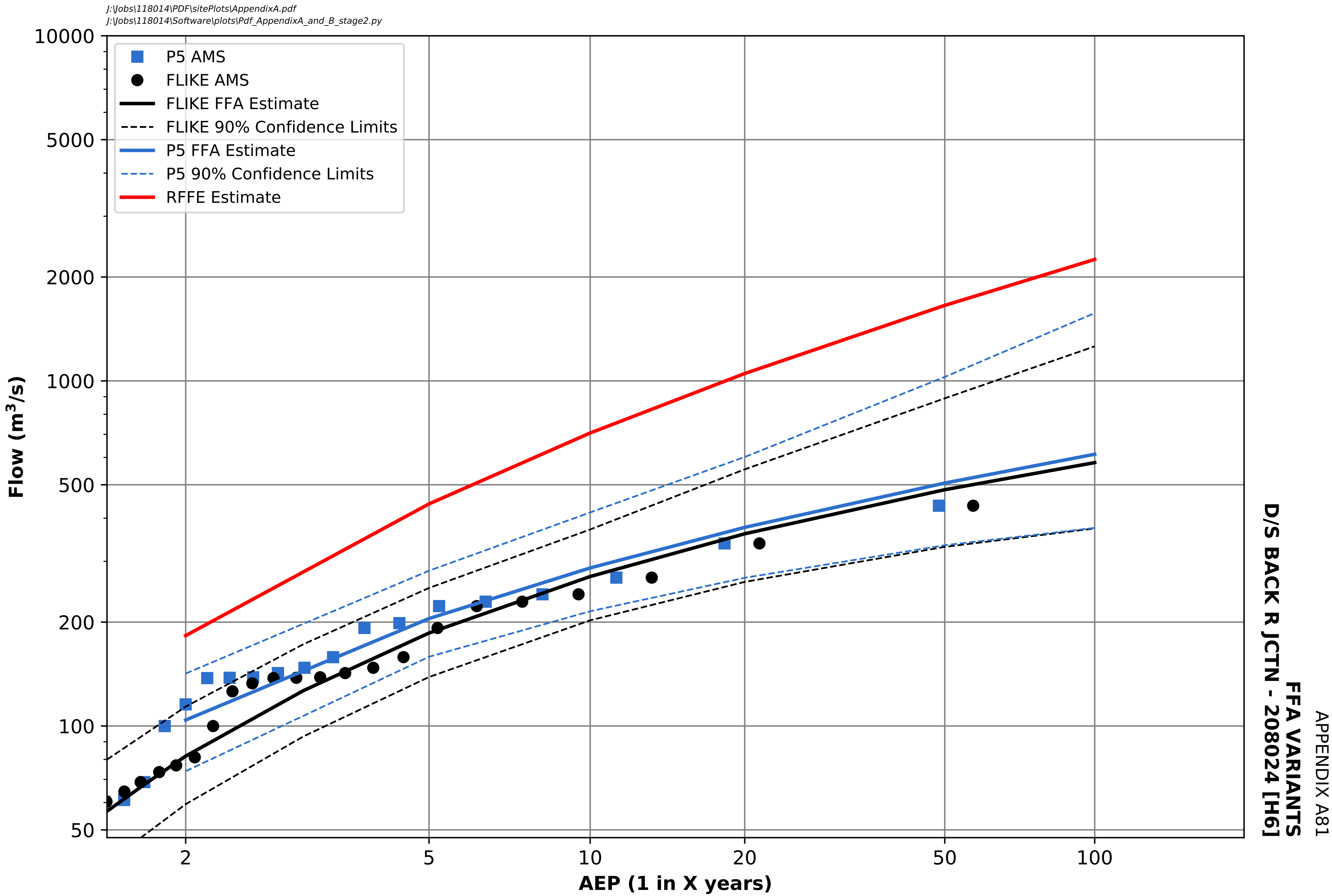


MONKERAI - 209001 [H5]
FFA VARIANTS
APPENDIX A80


J:\Jobs\118014\PDF\sitePlots\AppendixA.pdf
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
P5 AMS
FLIKE AMS
FLIKE FFA Estimate
FLIKE 90% Confidence Limits
P5 FFA Estimate
P5 90% Confidence Limits
RFFE Estimate
Flow (m³/s)
AEP (1 in X years)
10000
5000
2000
1000
500
200
100
50
2
5
10
20
50
100
D/S BACK R JCTN - 208024 [H6]
FFA VARIANTS
APPENDIX A81

J:\Jobs\118014\PDF\sitePlots\AppendixA.pdf
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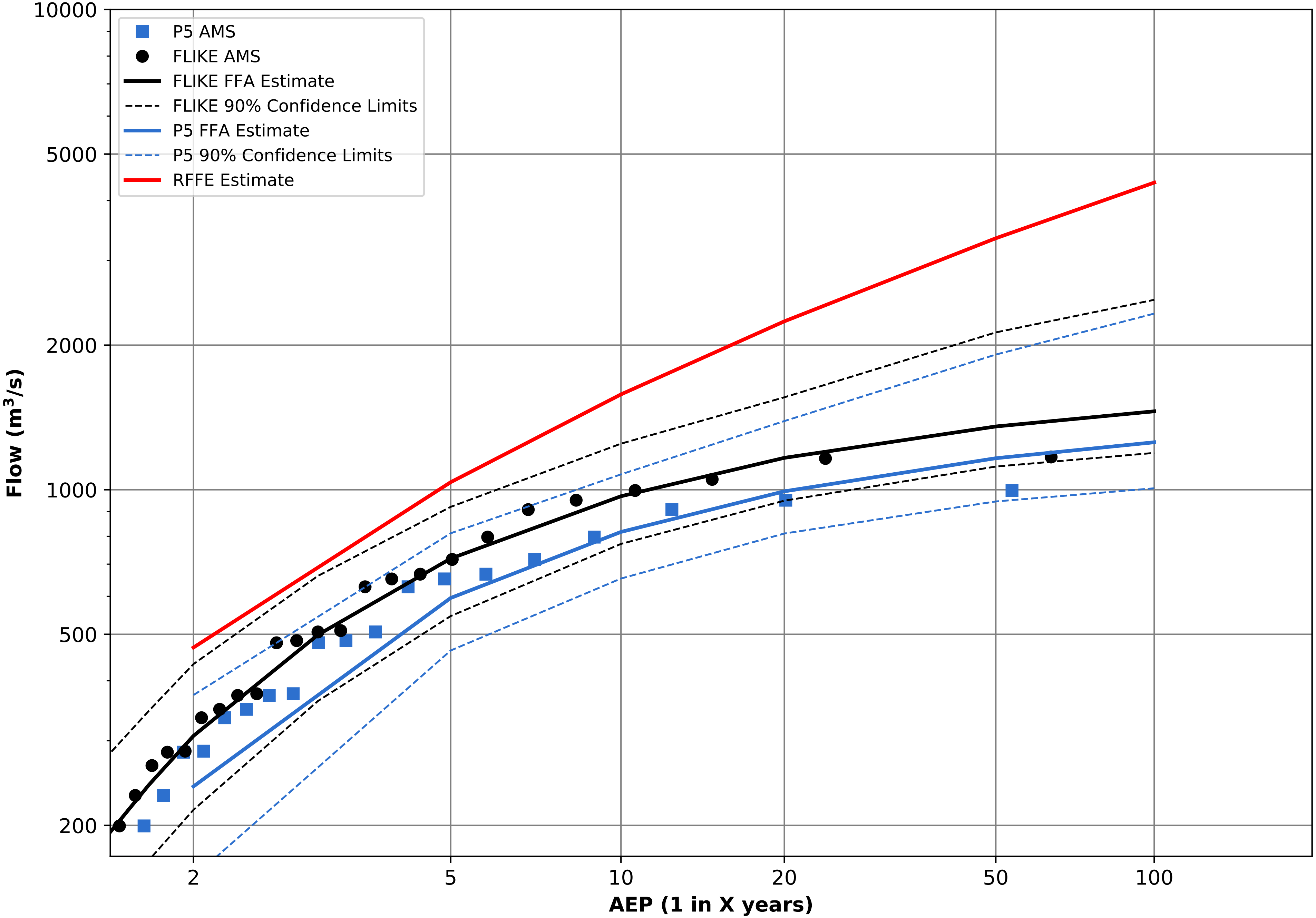
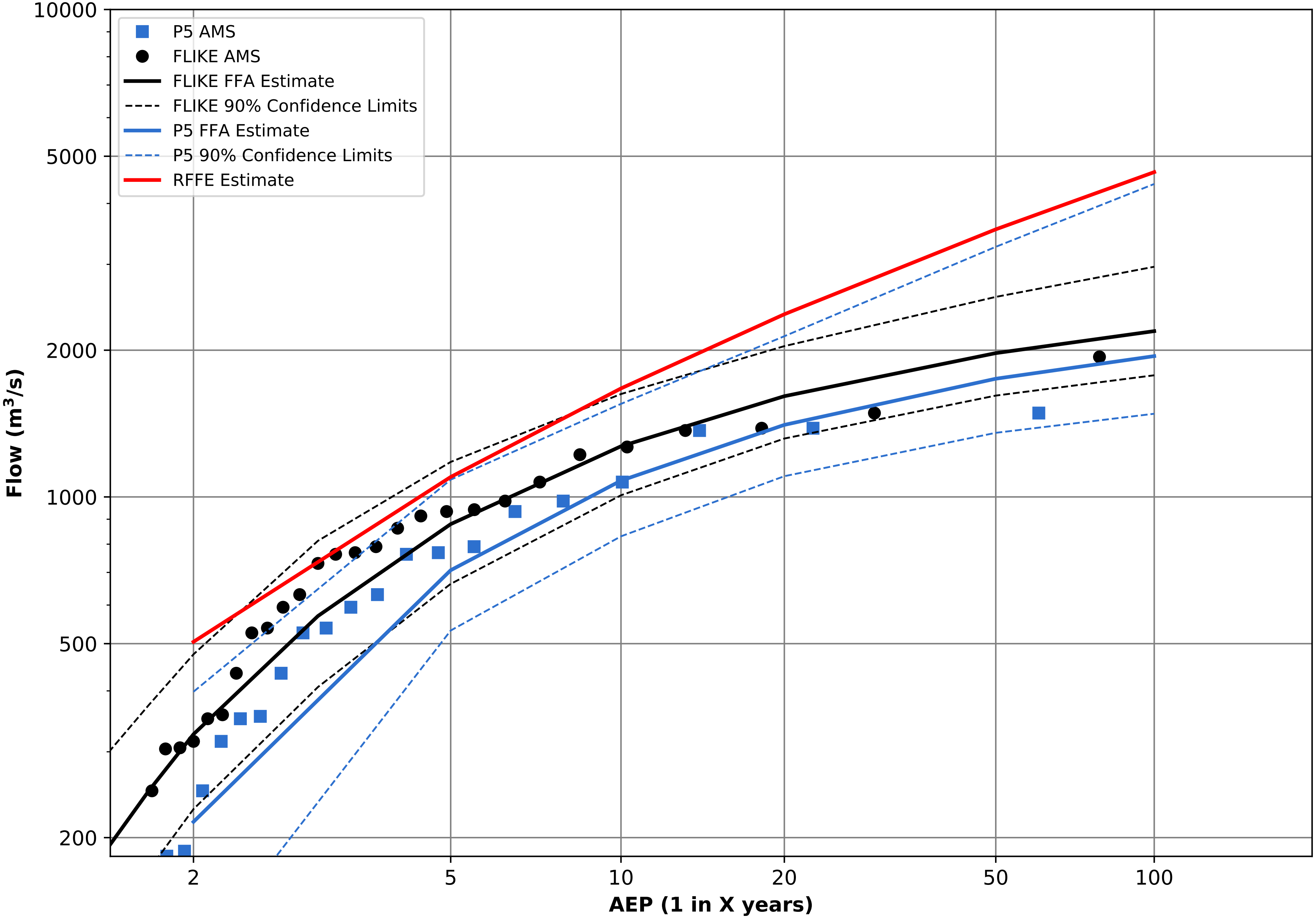


DAM SITE - 209018 [H7]
FFA VARIANTS
APPENDIX A82



BIRDWOOD(FILLY FLAT) - 207006 [H8]
FFA VARIANTS

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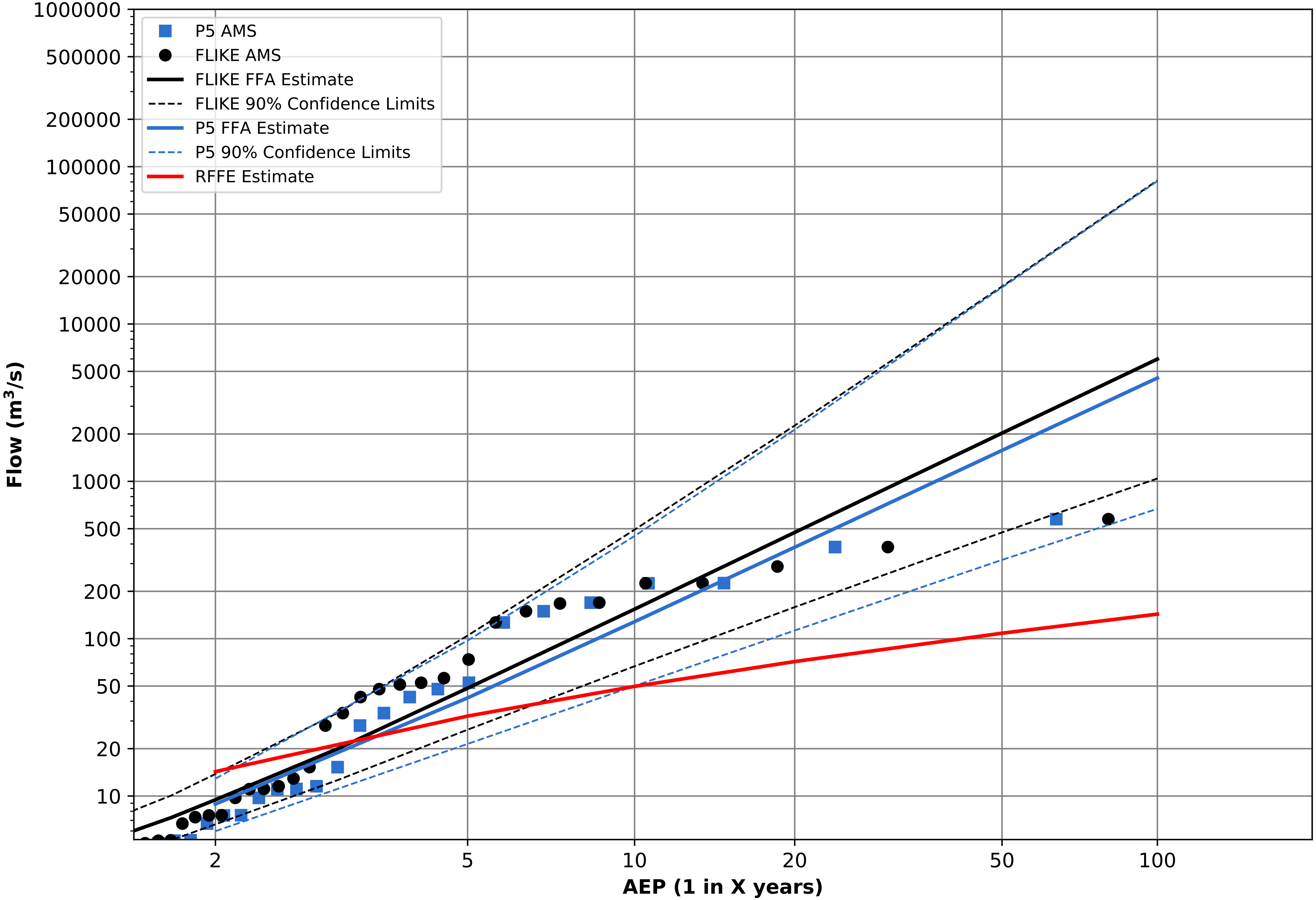
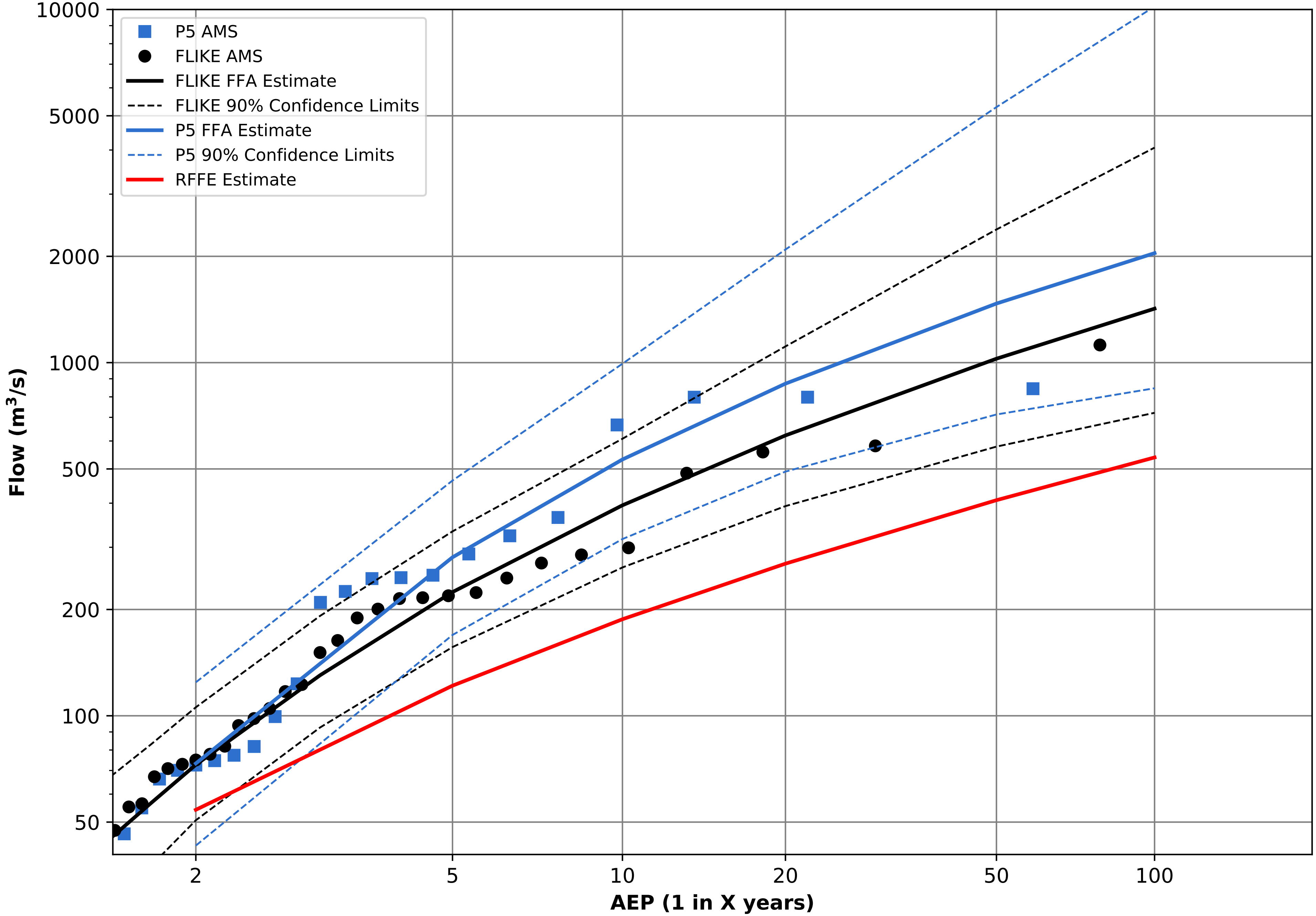


THE ROCKS NO.2 - 210084 [H9]

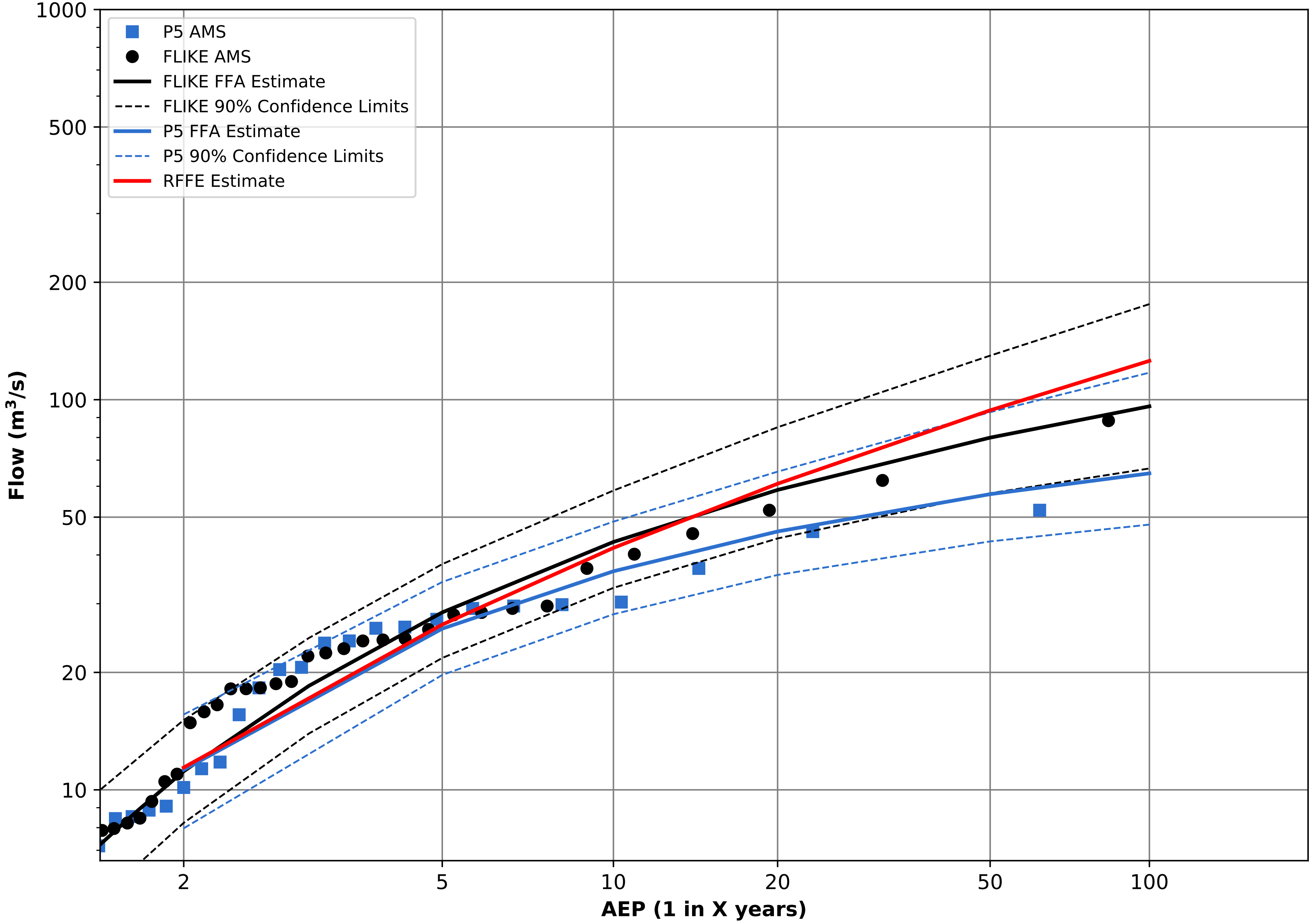
FFA VARIANTS

APPENDIX A84



U/S GLENDON BROOK - 210080 [H10]
FFA VARIANTS

APPENDIX A85



LIDDELL - 210076 [H11]

FFA VARIANTS

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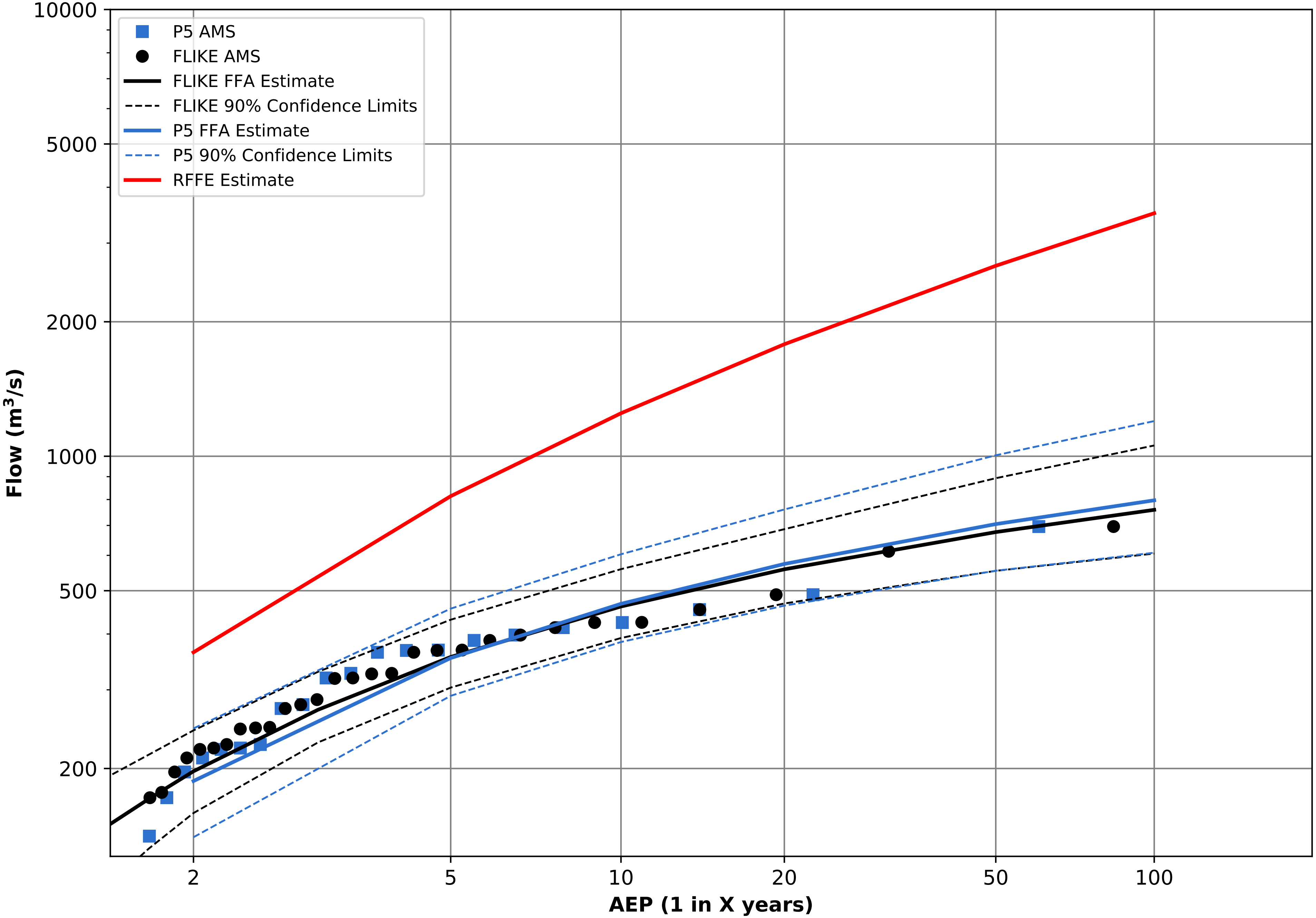
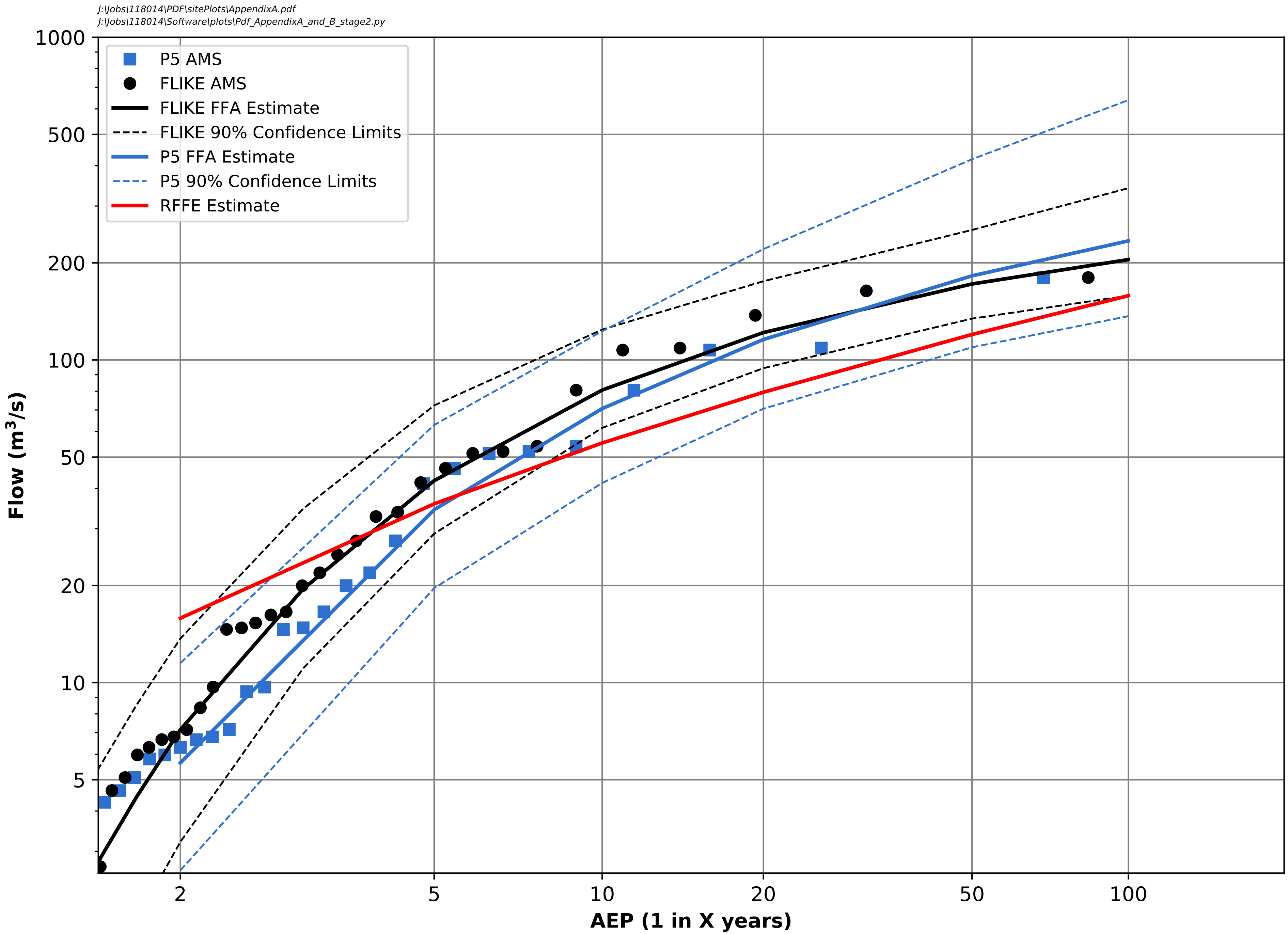


APPENDIX A87

FFA VARIANTS

CROSSING - 209002 [H12]



POKOLBIN SITE 3 - 210068 [H13]
FFA VARIANTS

APPENDIX A88

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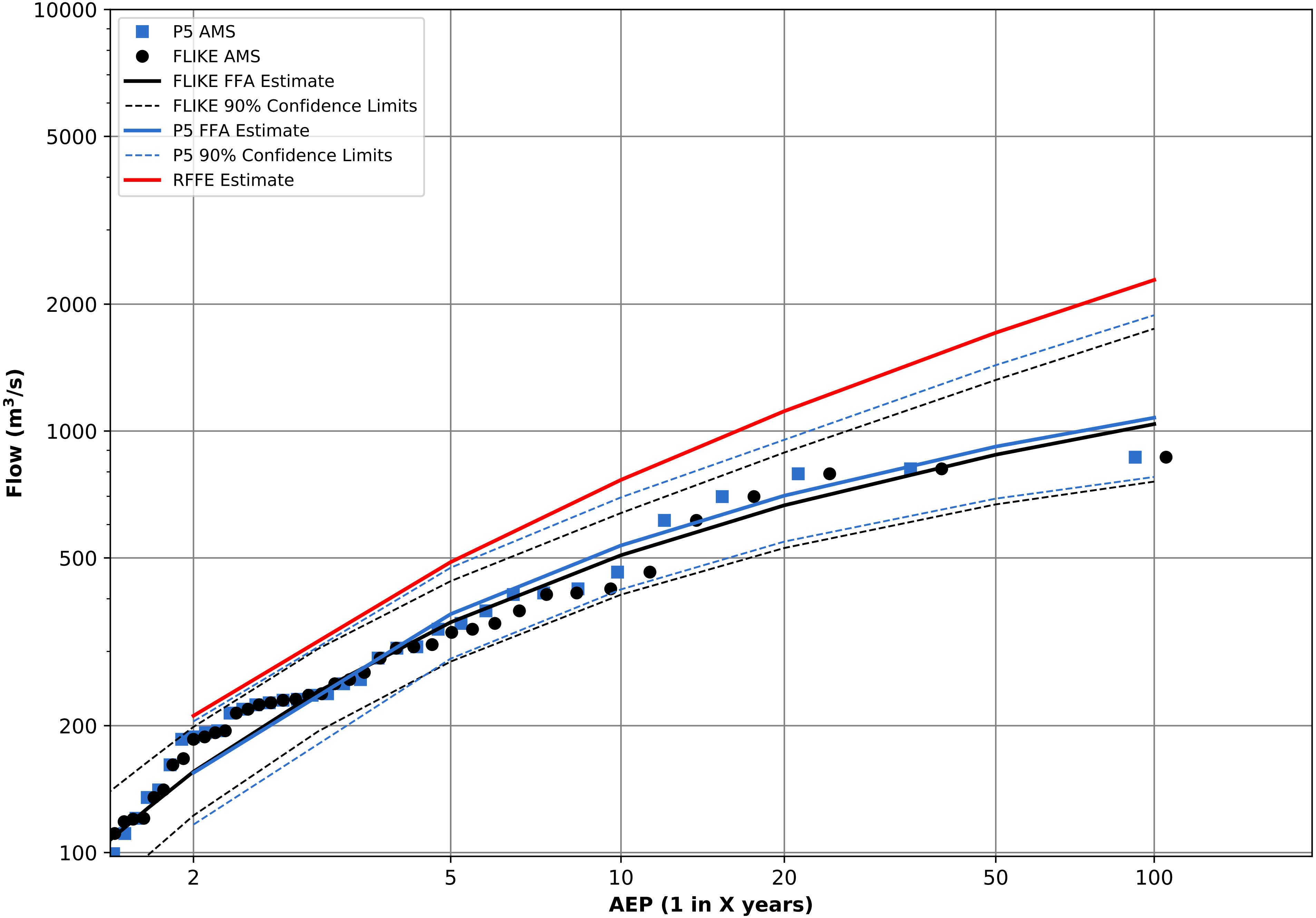

MIDDLE FALBROOK(FAL DAM SI - 210044 [H14]

FFA VARIANTS

APPENDIX A89

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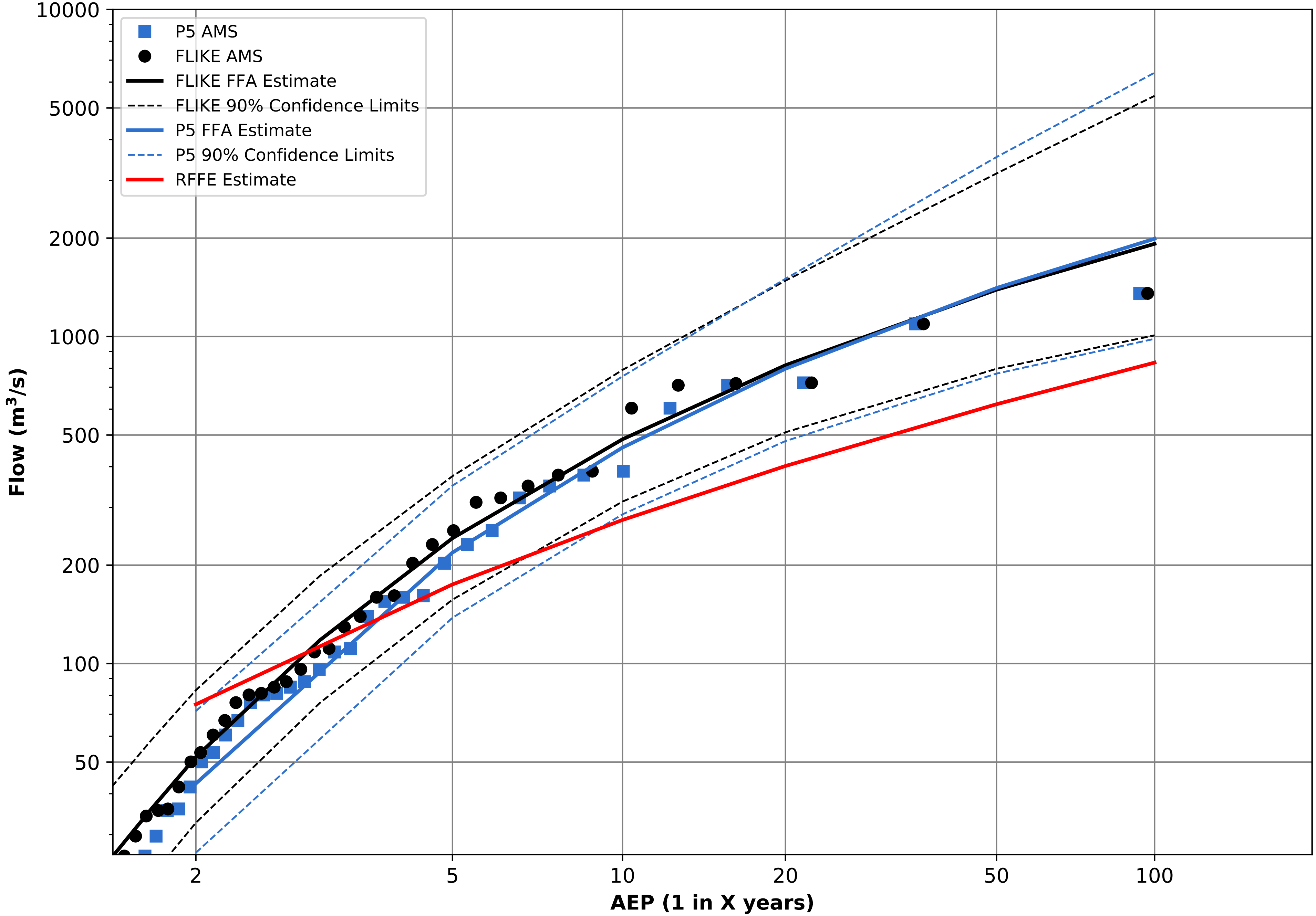

FFA VARIANTS

WYBONG - 210040 [H15]

APPENDIX A90

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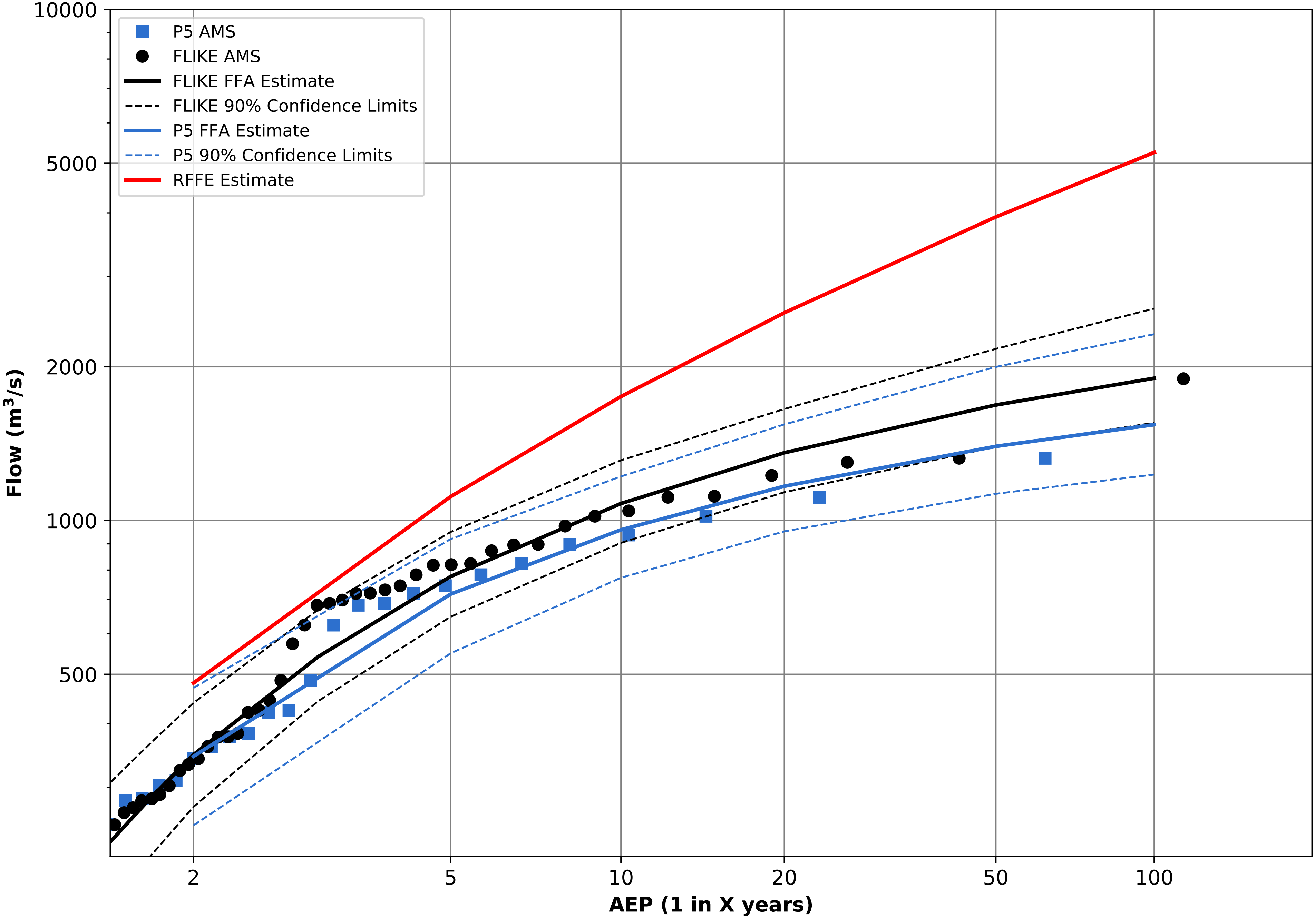
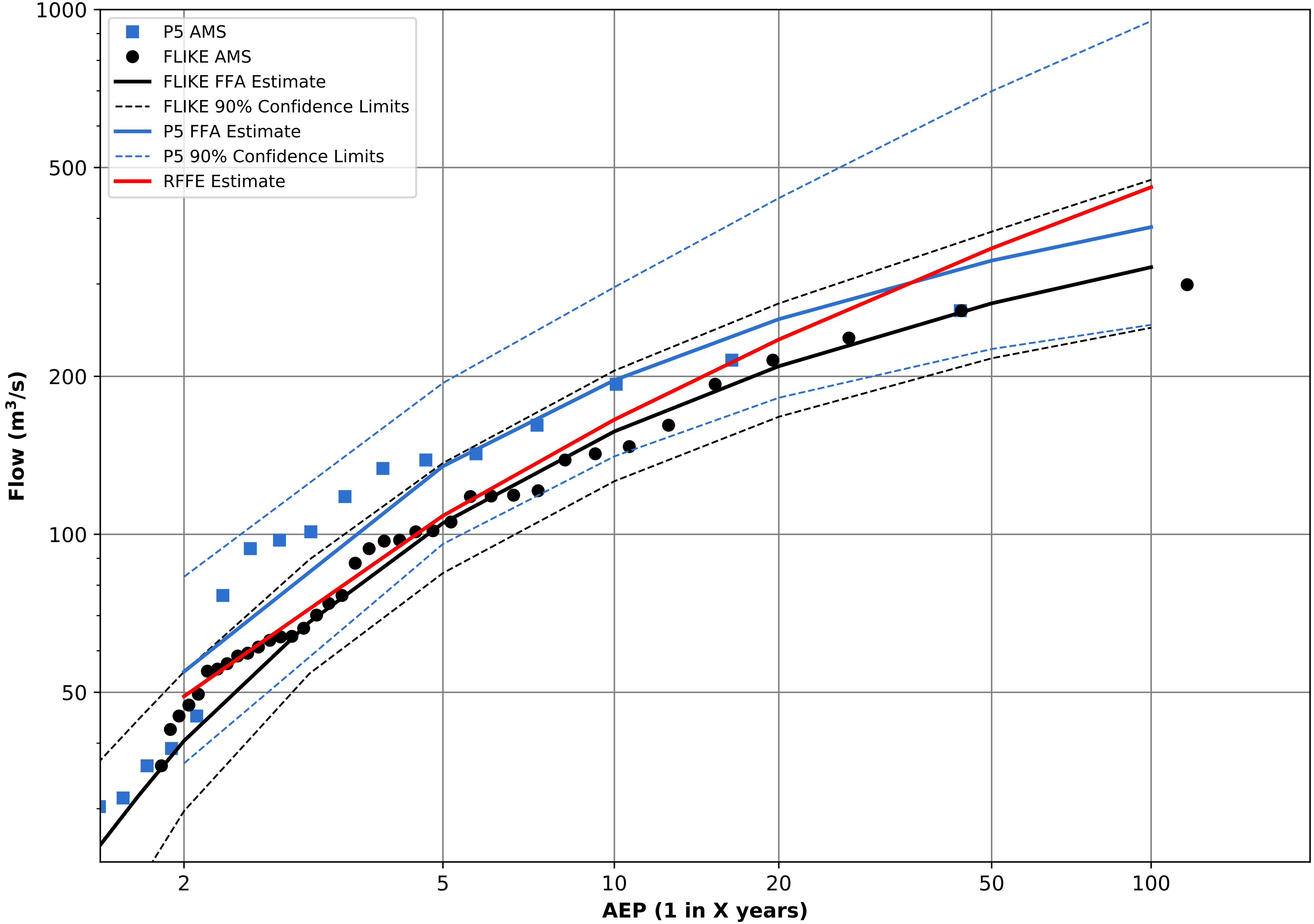


APPENDIX A91

FFA VARIANTS

GOSTWYCK - 210079 [H16]



APPENDIX A92

FFA VARIANTS

BARRY - 208009 [H17]

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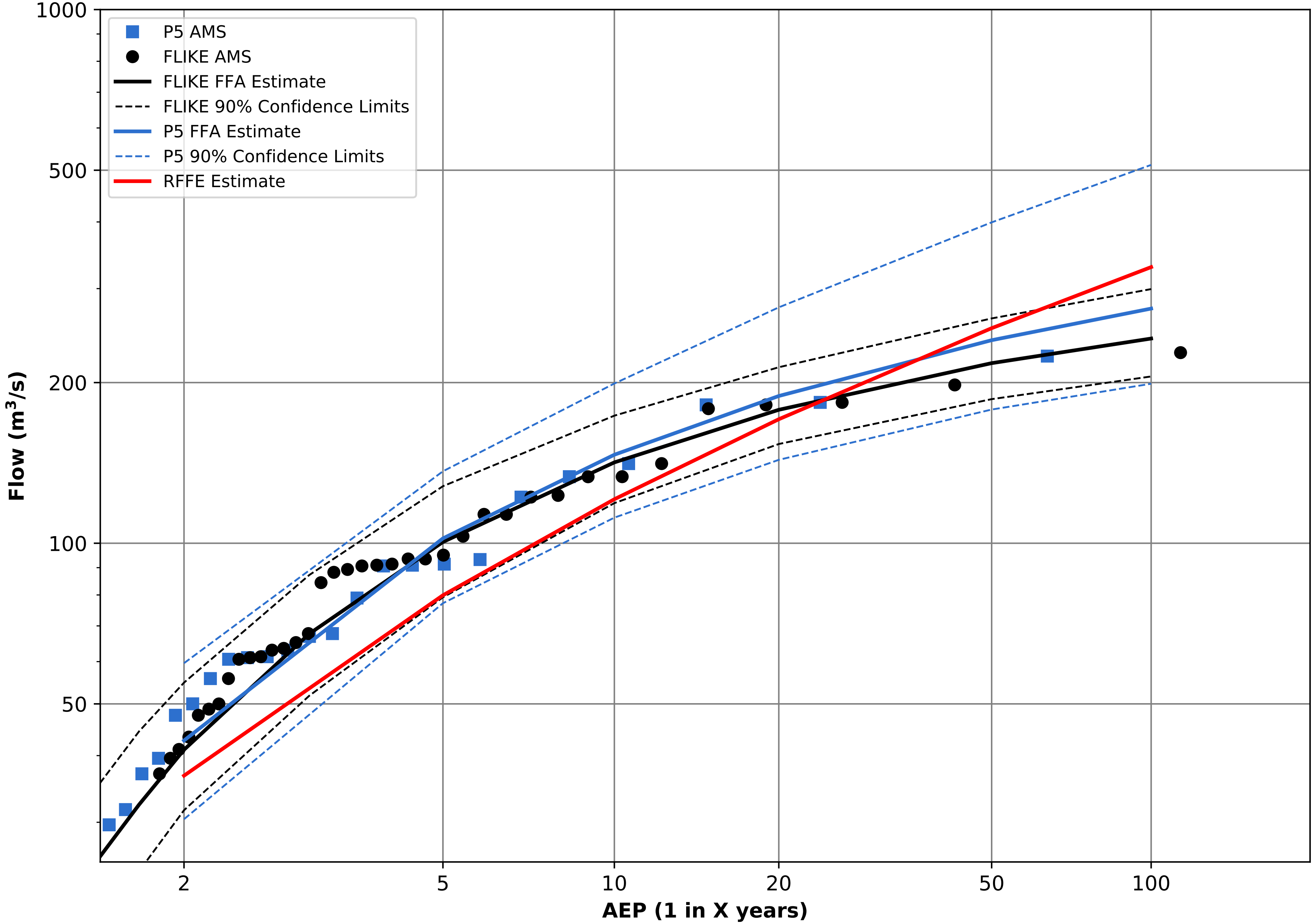

NOWENDOC - 208007 [H18]
FFA VARIANTS
APPENDIX A93

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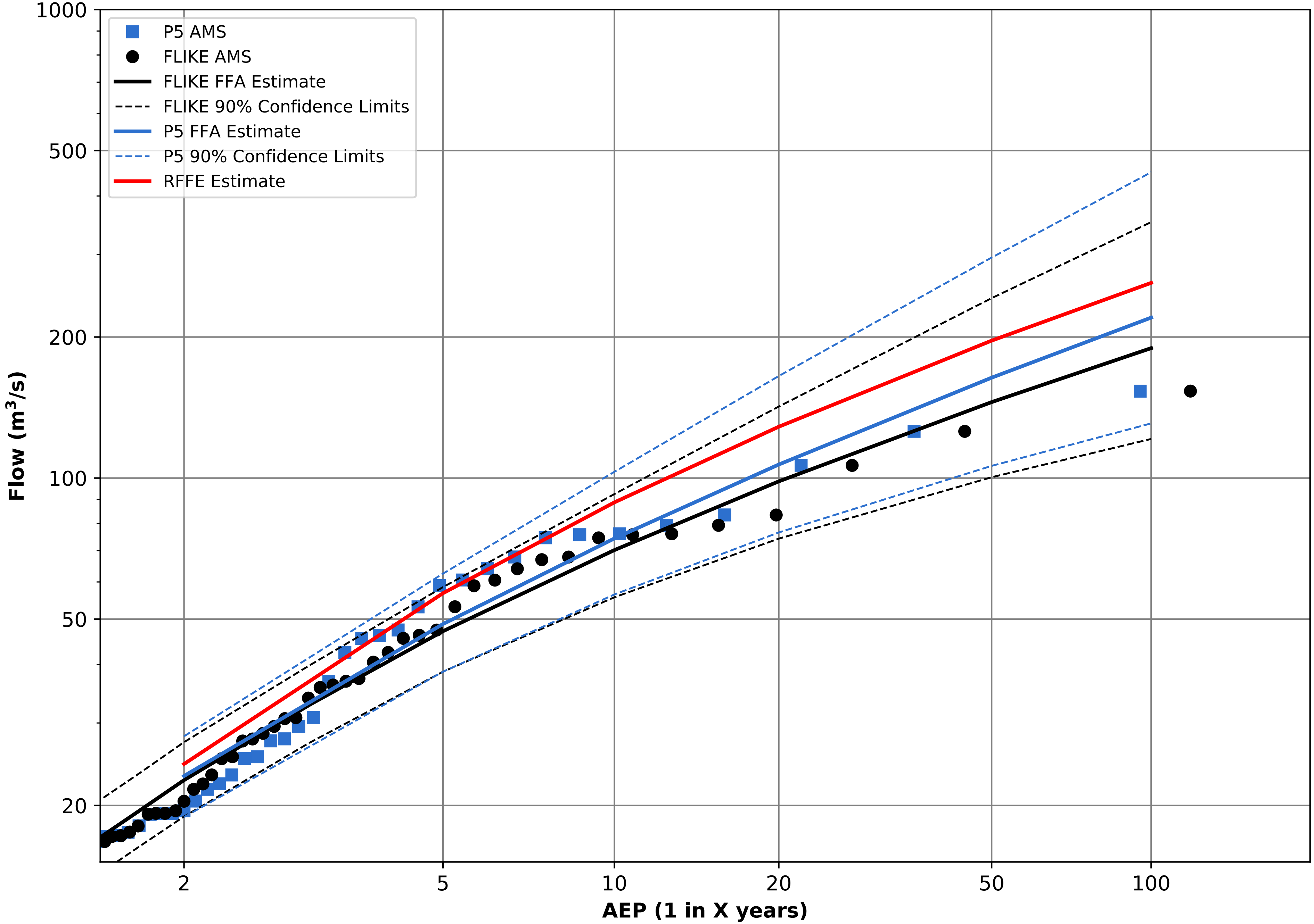
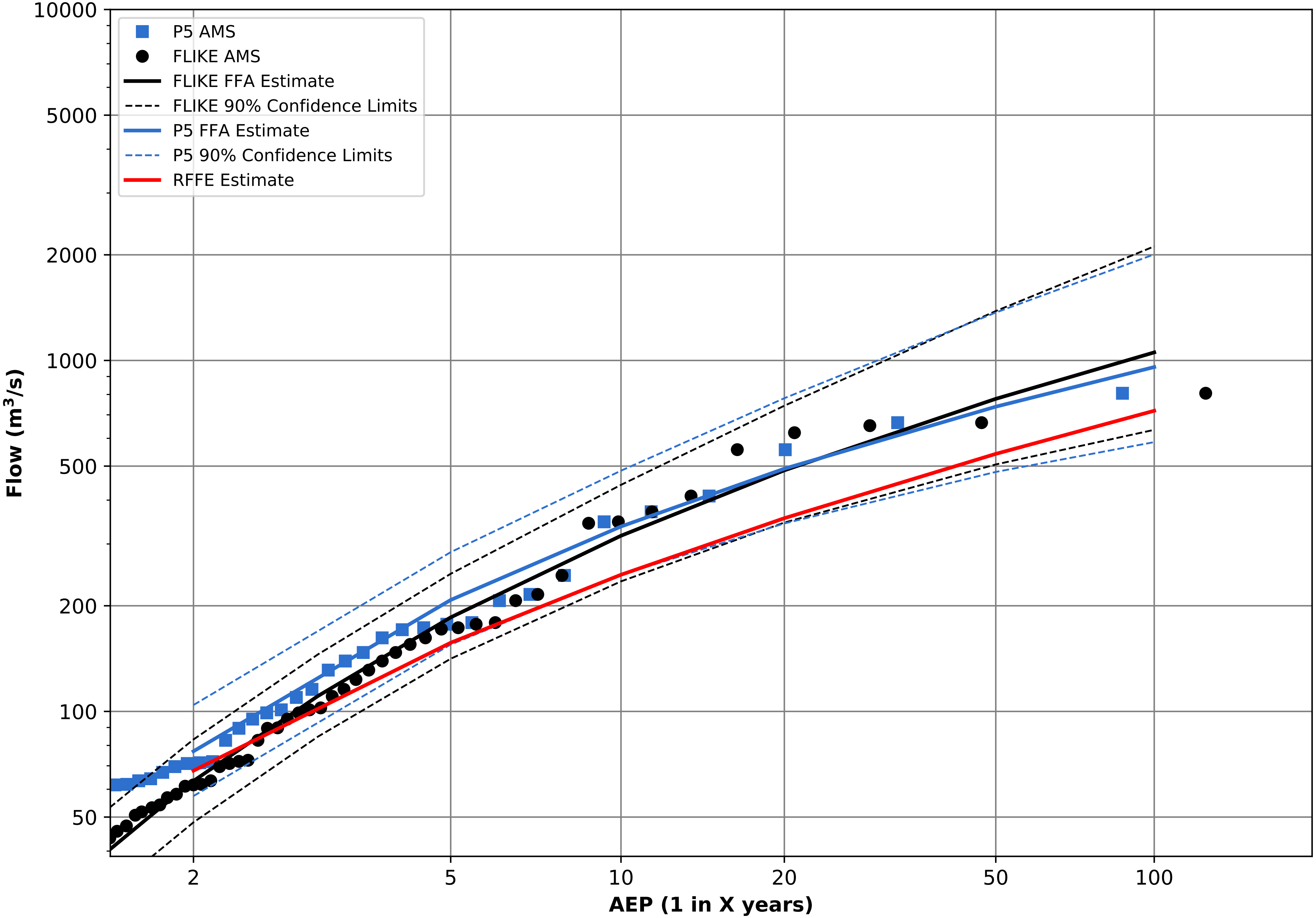


BOBS CROSSING - 208001 [H19]

FFA VARIANTS

APPENDIX A94



ROUCHEL BROOK (THE VALE) - 210014 [H20]
FFA VARIANTS

APPENDIX A95

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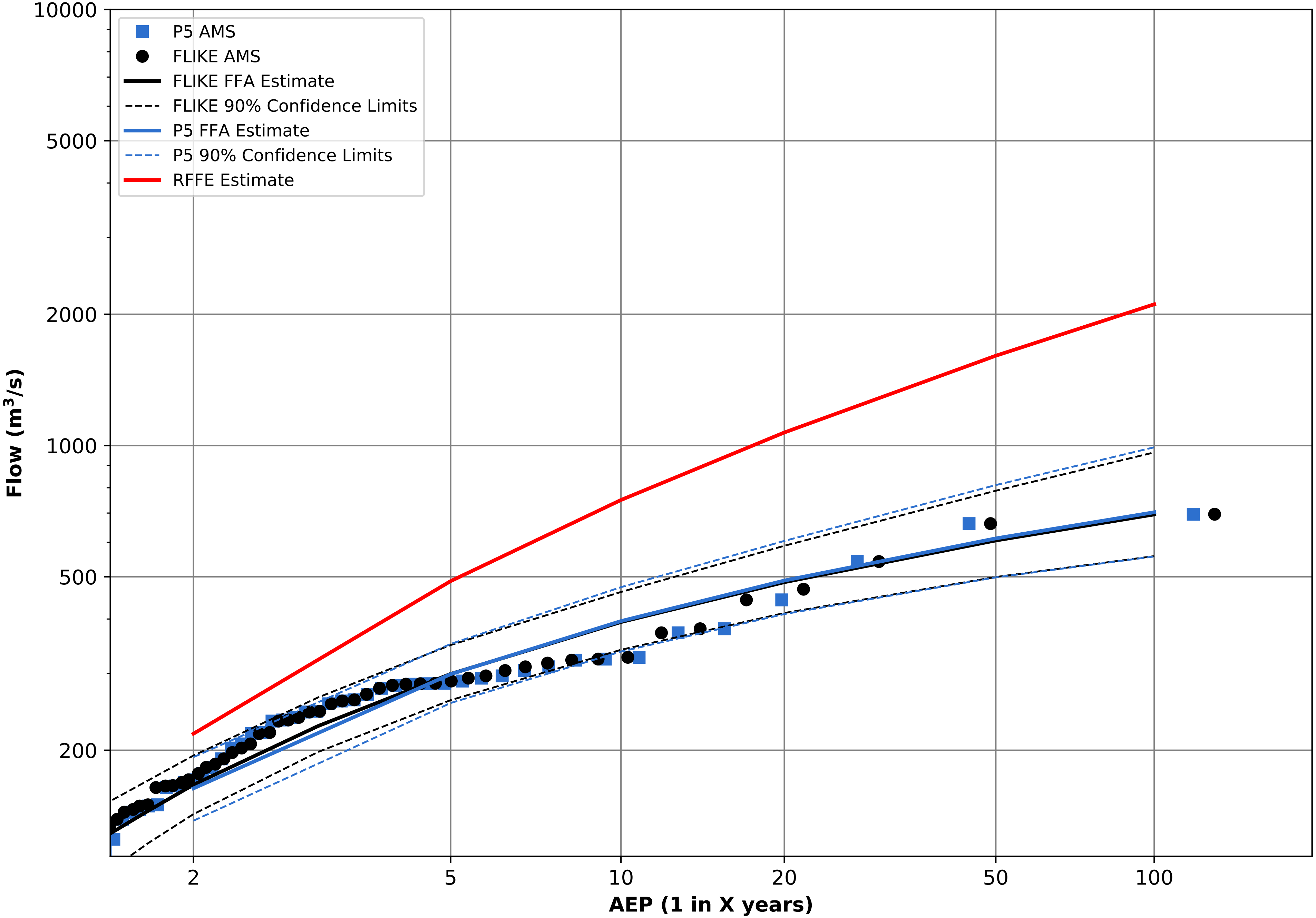

HALTON - 210022 [H21]
FFA VARIANTS
APPENDIX A96

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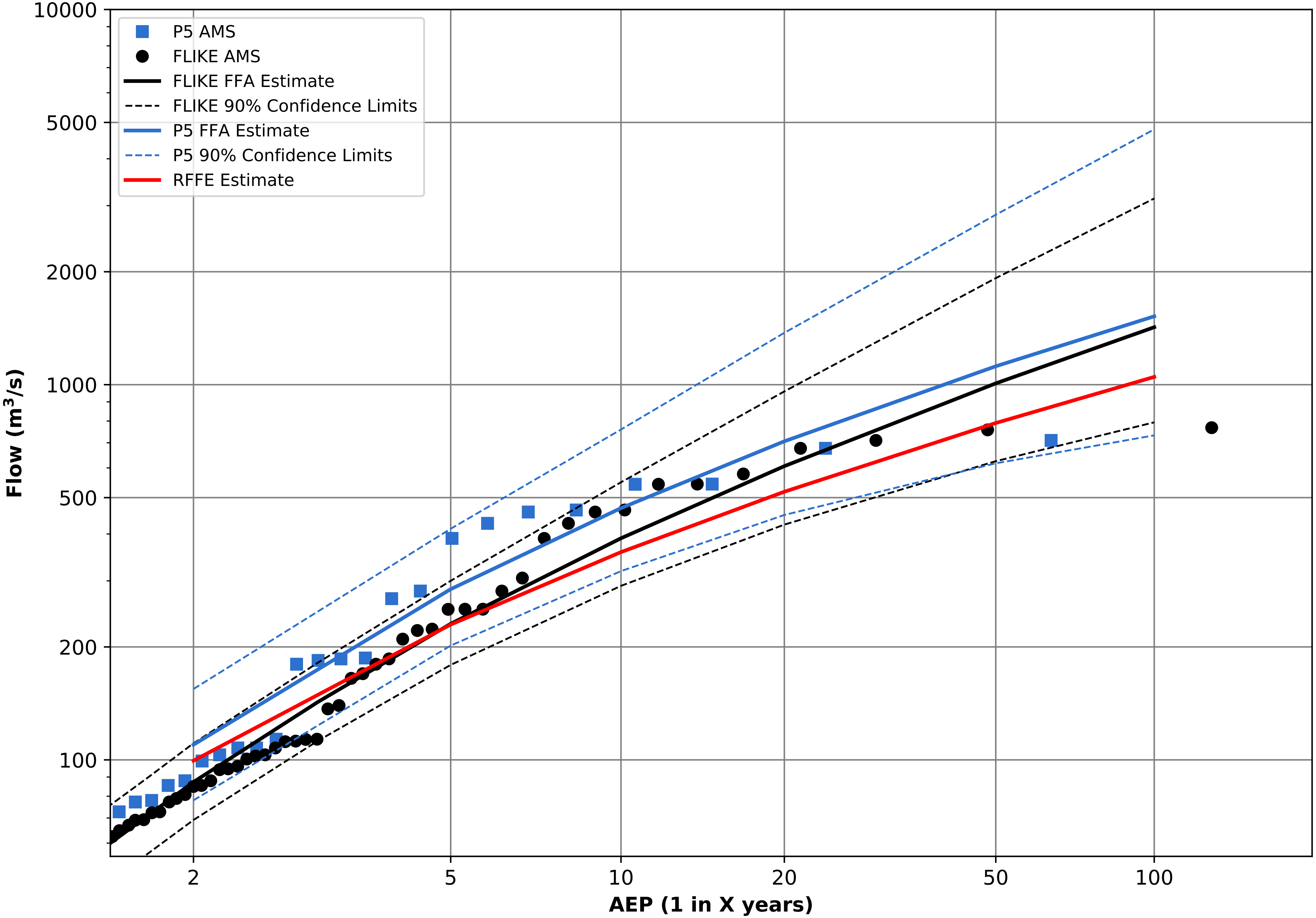

MOONAM DAM SITE - 210018 [H22]
FFA VARIANTS

APPENDIX A97

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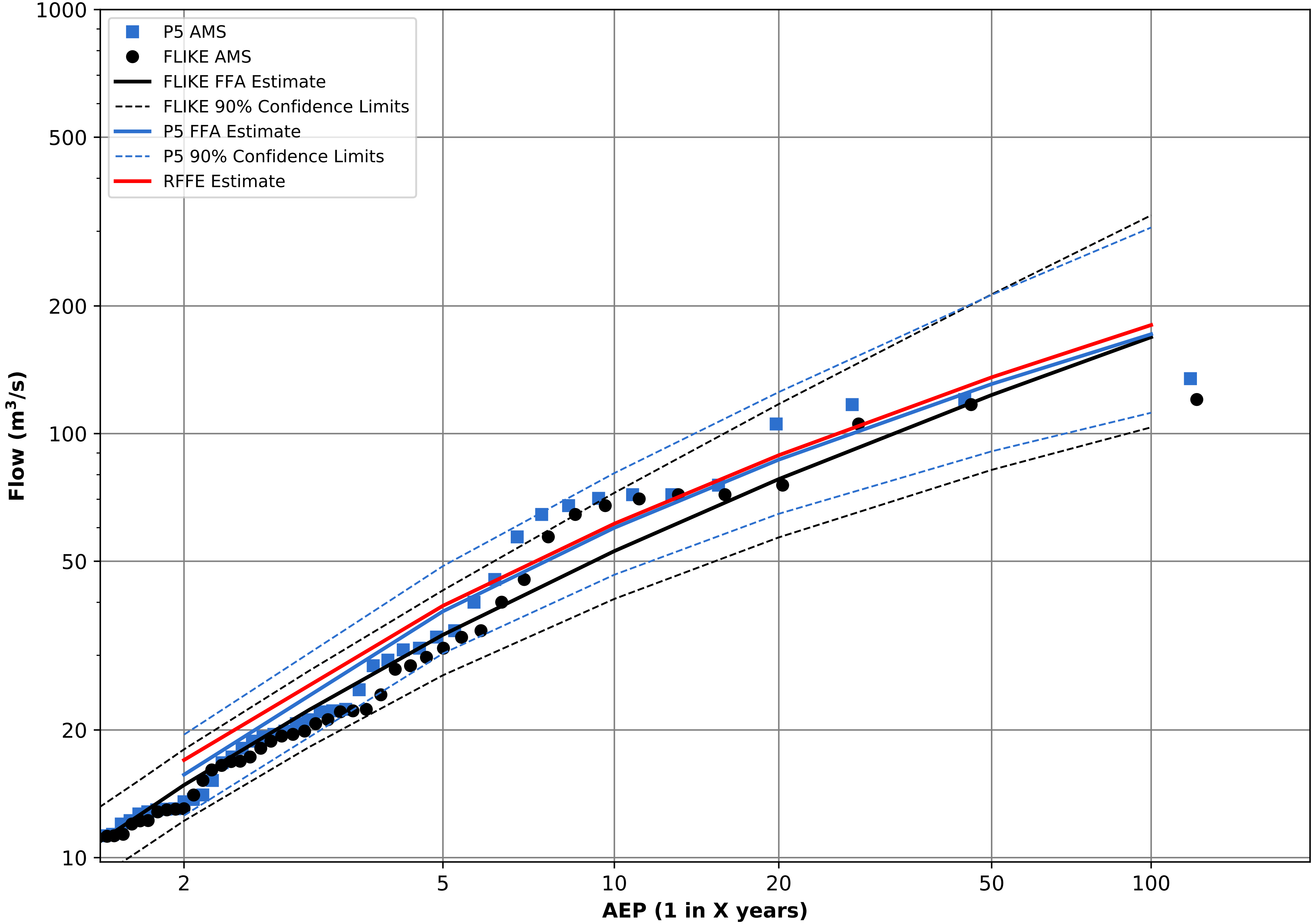

MOONAN BROOK - 210017 [H23]

FFA VARIANTS

APPENDIX A98

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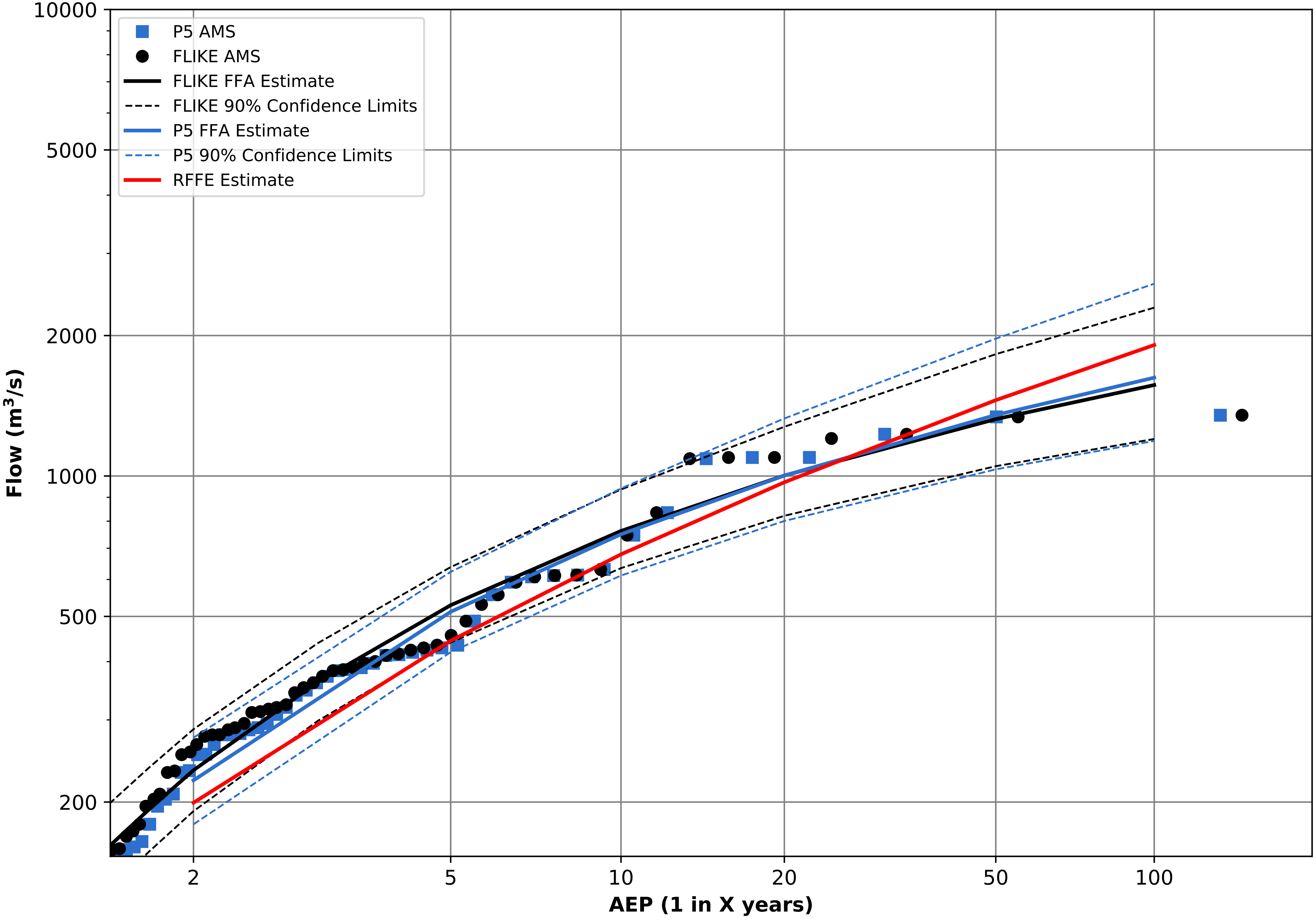
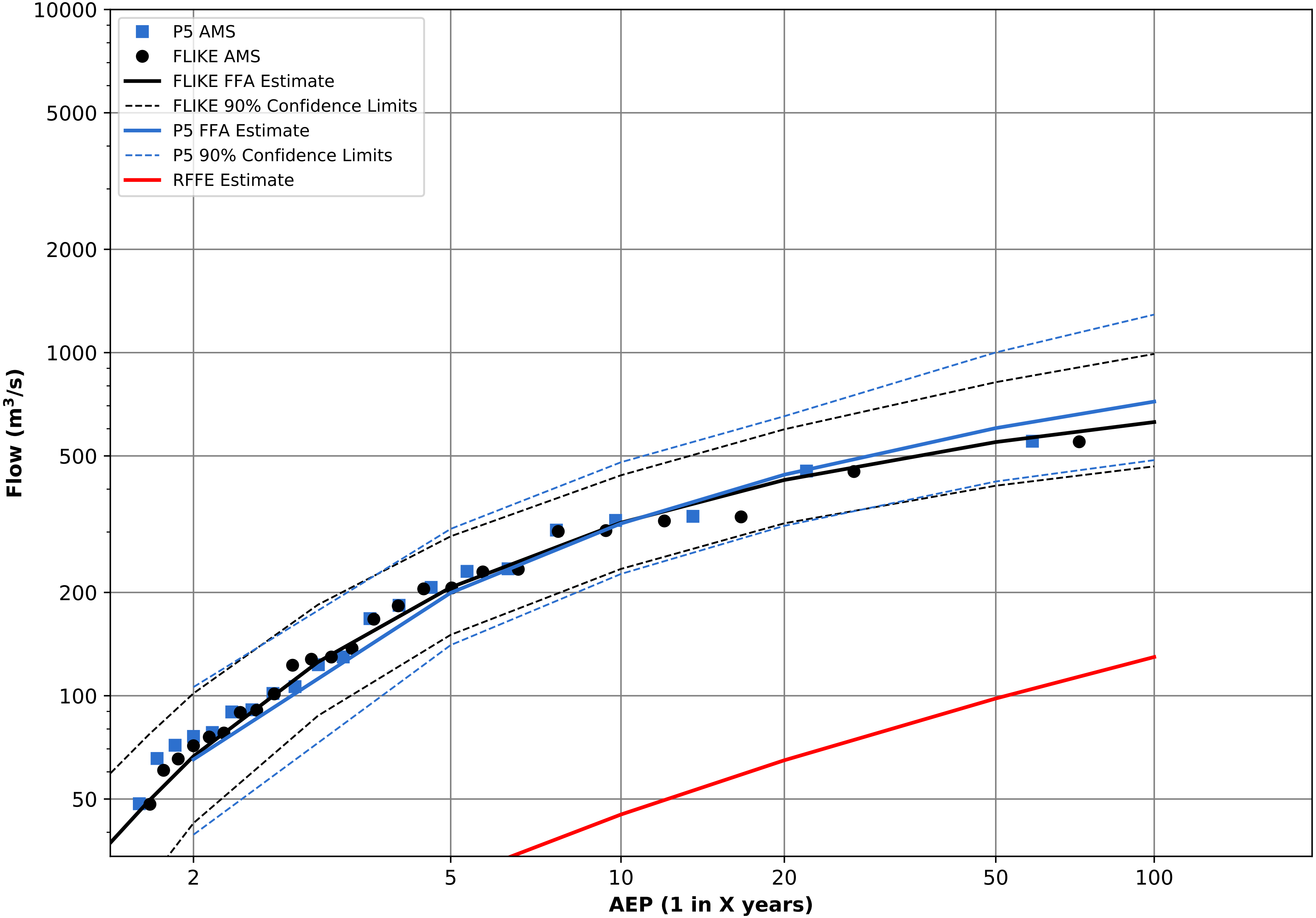


TILLEGRA - 210011 [H24]

FFA VARIANTS

APPENDIX A99



YARRAMALONG - 211014 [H25]
FFA VARIANTS

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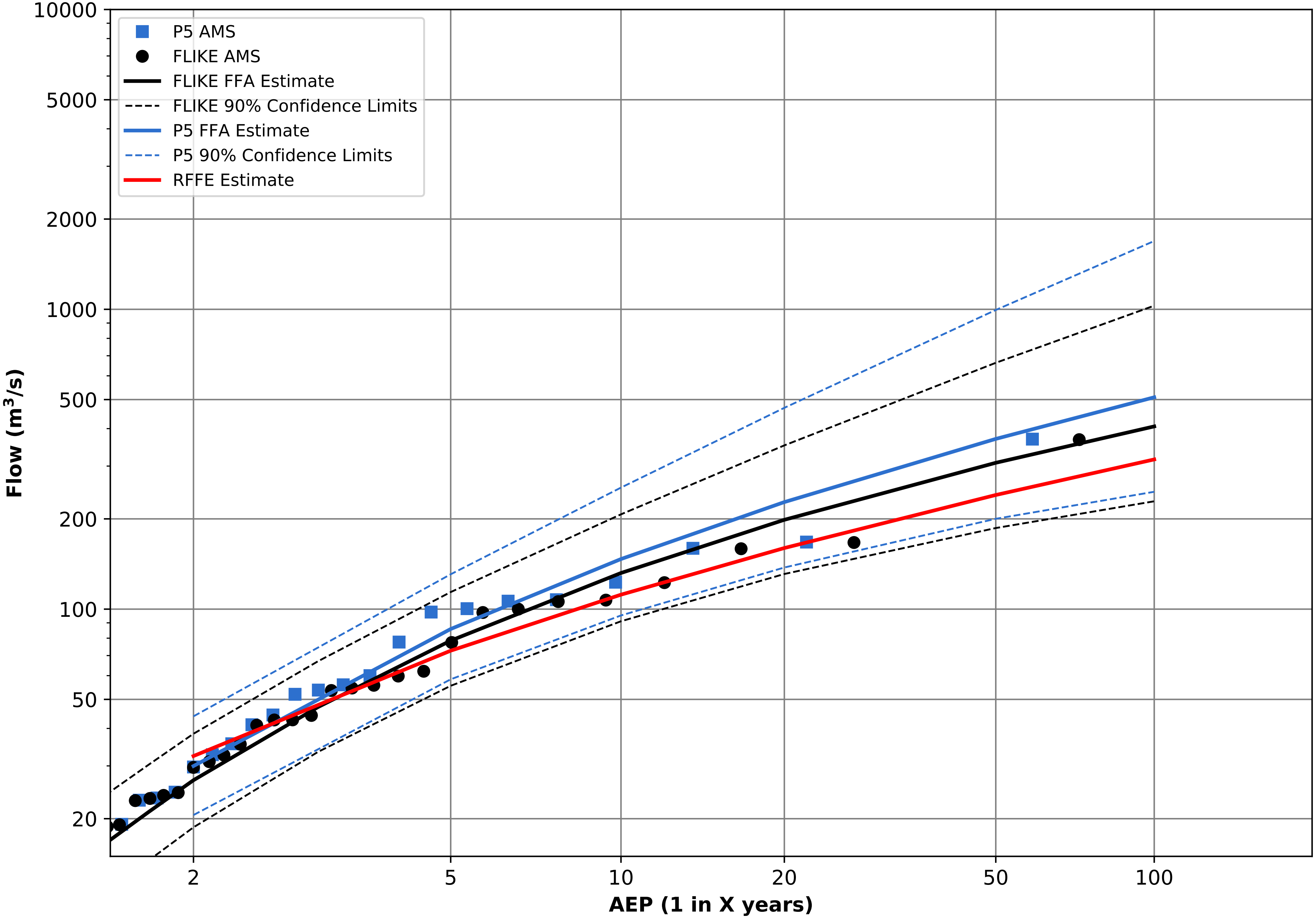

APPENDIX A101
FFA VARIANTS
U/S WEIR - 211013 [H26]

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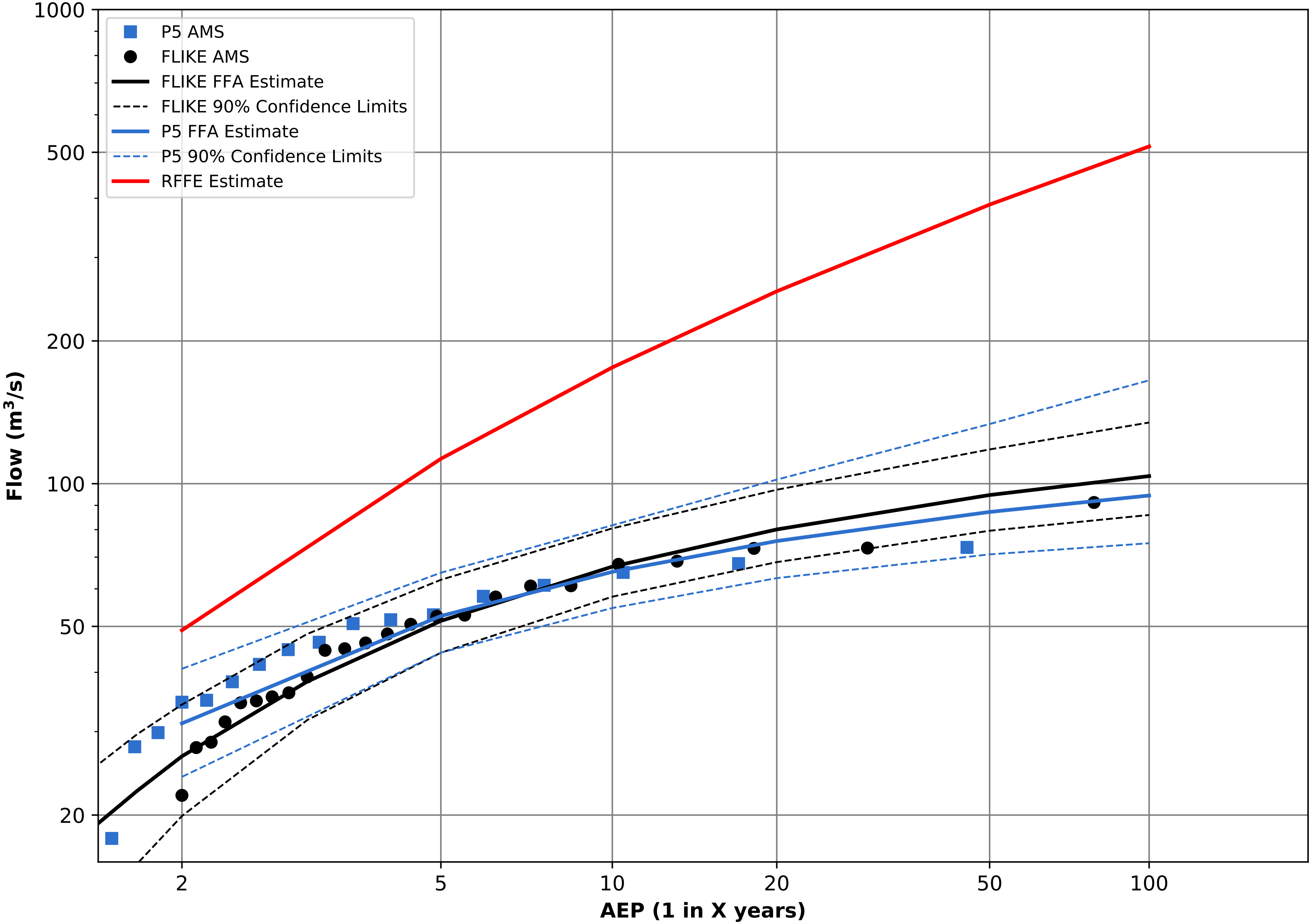

U/S WYONG R (DURREN LA) - 211010 [H27]

FFA VARIANTS

APPENDIX A102

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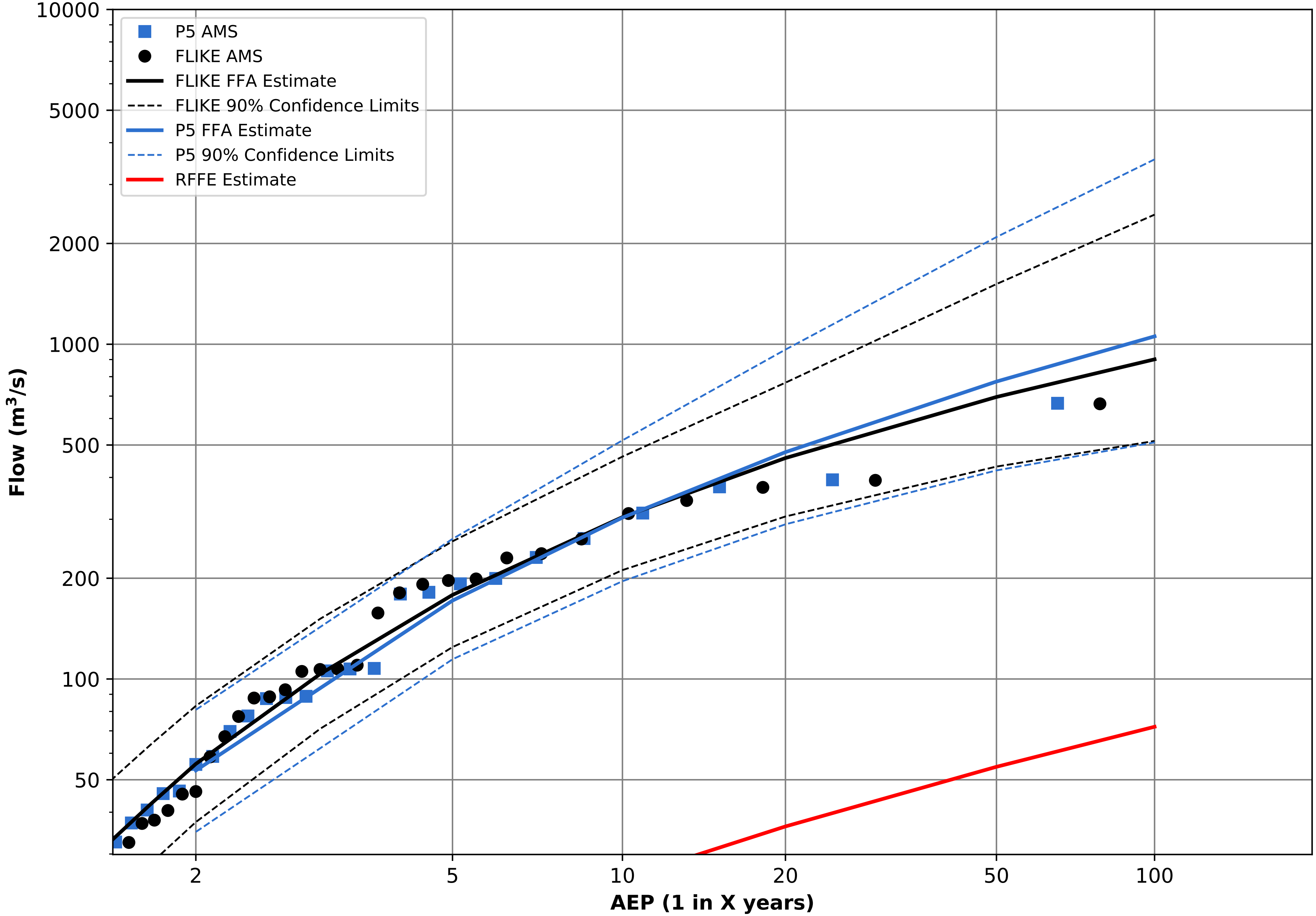

APPENDIX A103

FFA VARIANTS

GRACEMERE - 211009 [H28]

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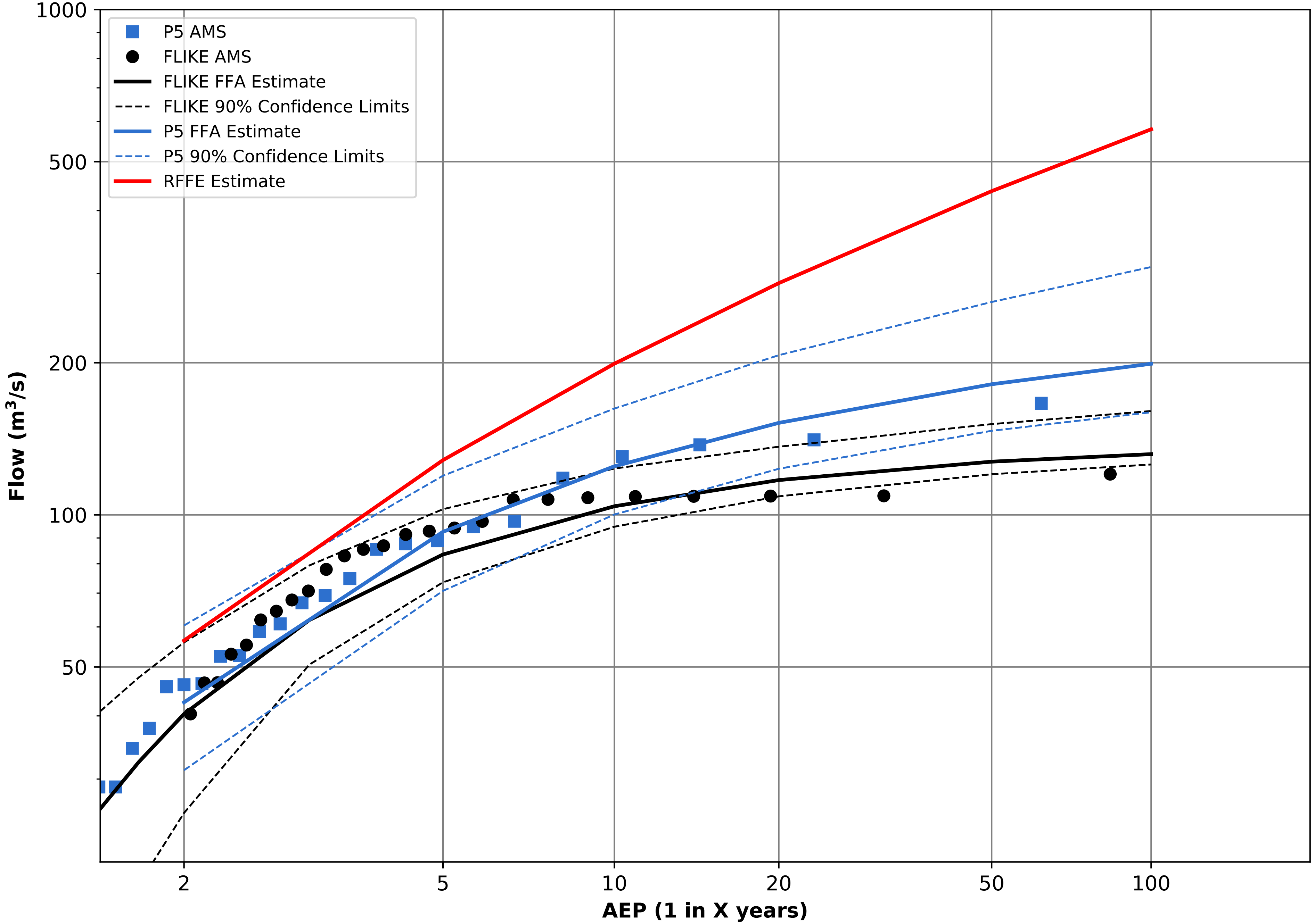
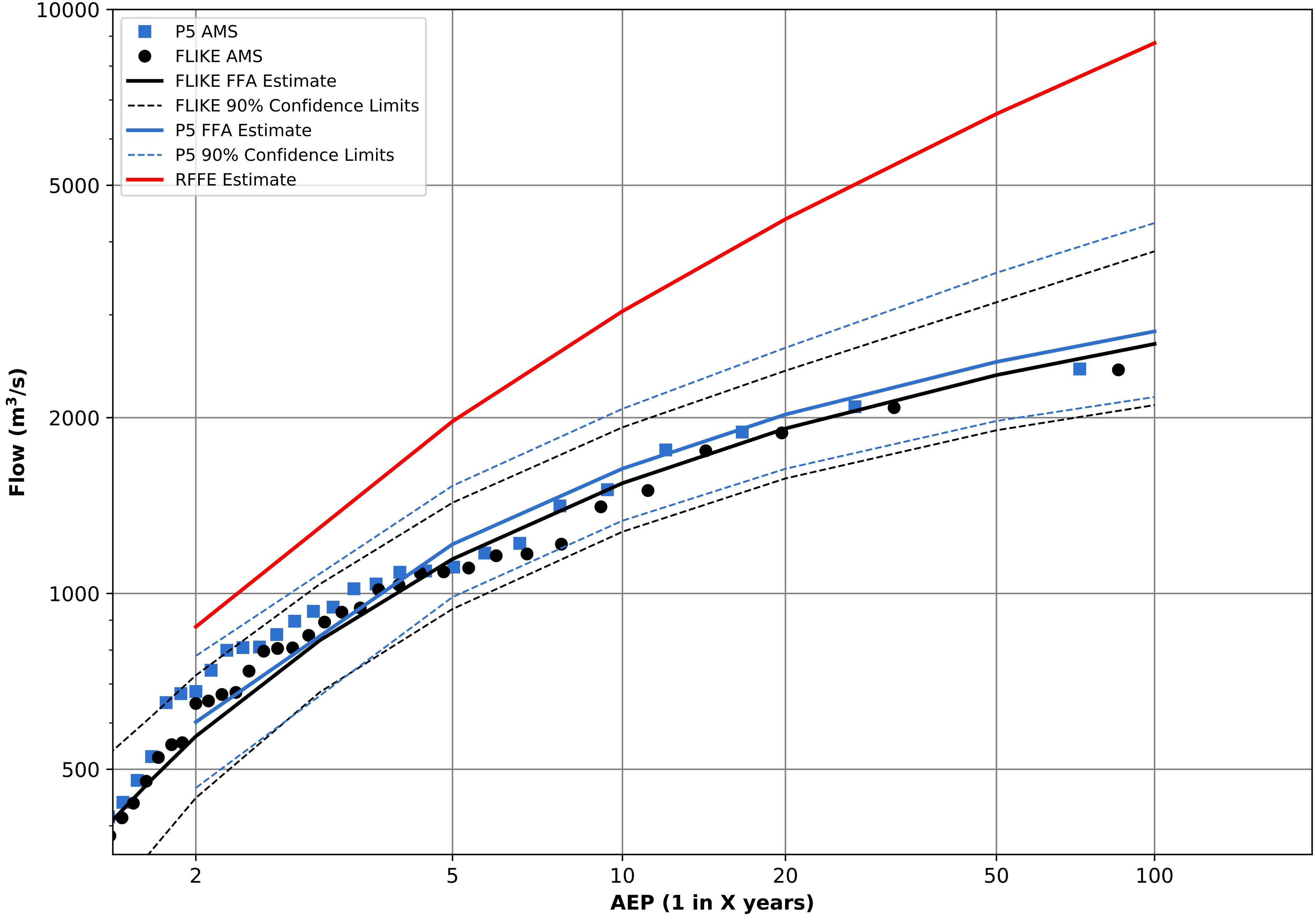


AVONDALE - 211008 [H29]
FFA VARIANTS
APPENDIX A104



BOORAL - 209003 [H30]
FFA VARIANTS
APPENDIX A105

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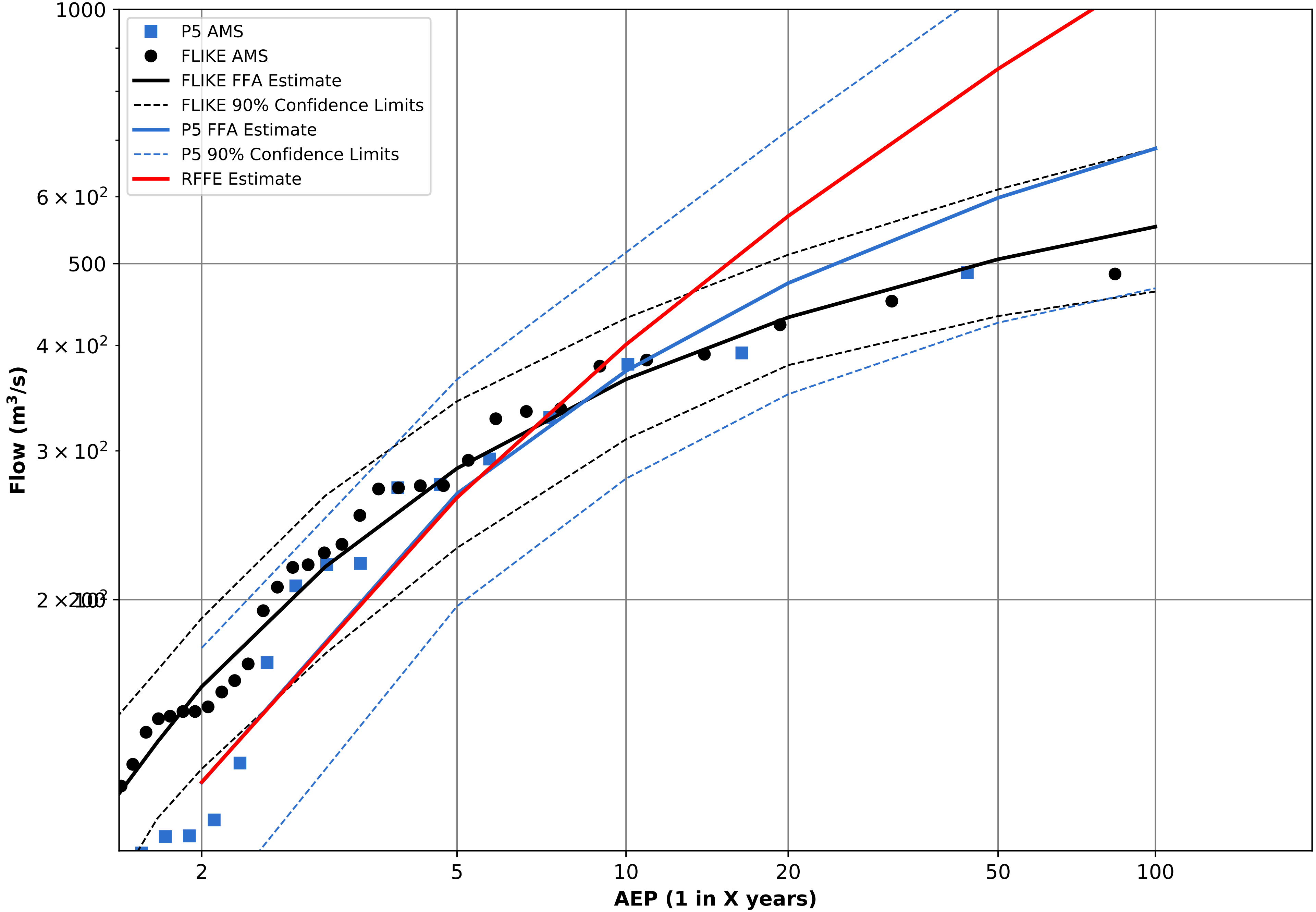

LANDSDOWNE - 208015 [H31]
FFA VARIANTS
APPENDIX A106

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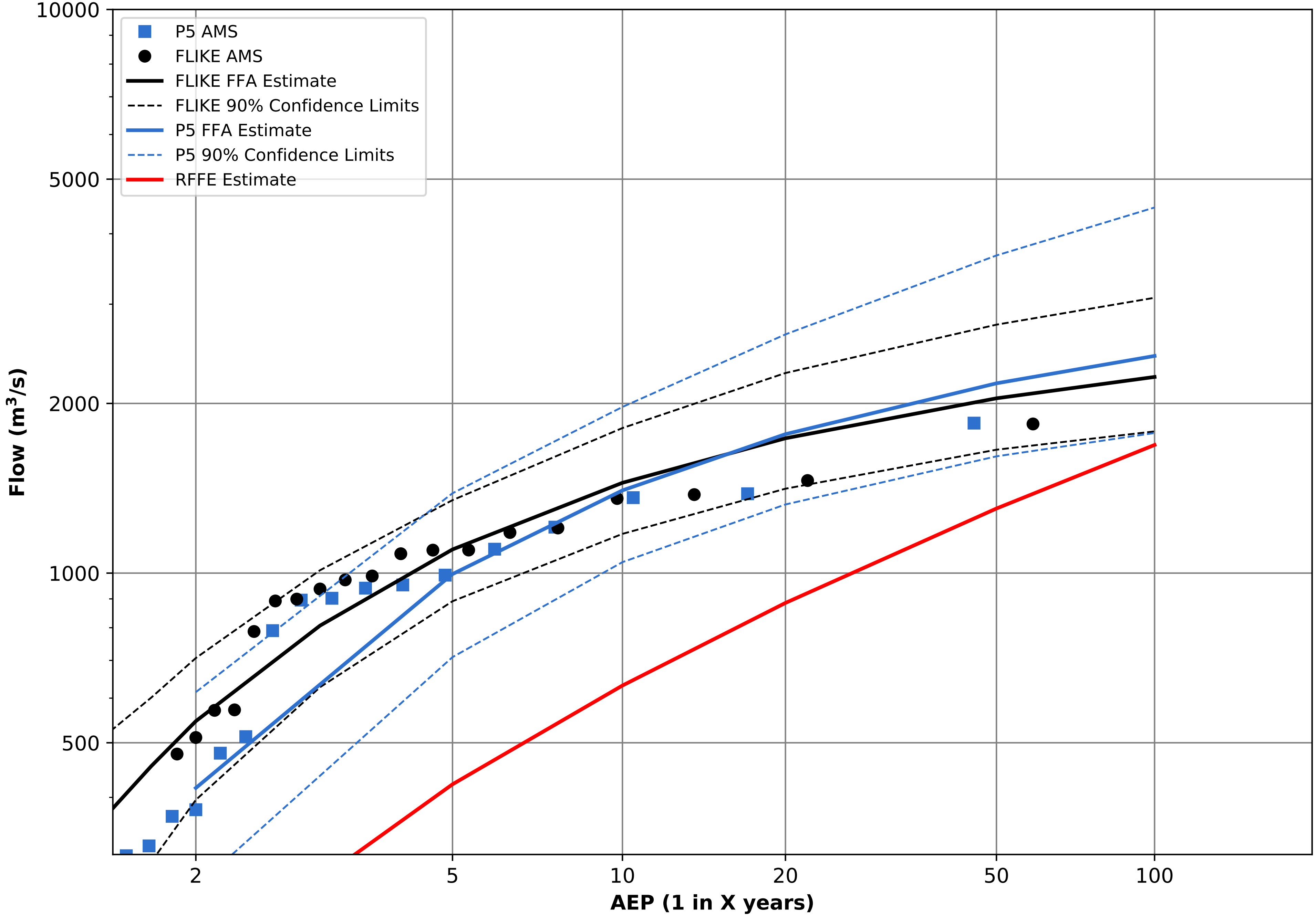

AVENEL - 207014 [H32]

FFA VARIANTS

APPENDIX A107

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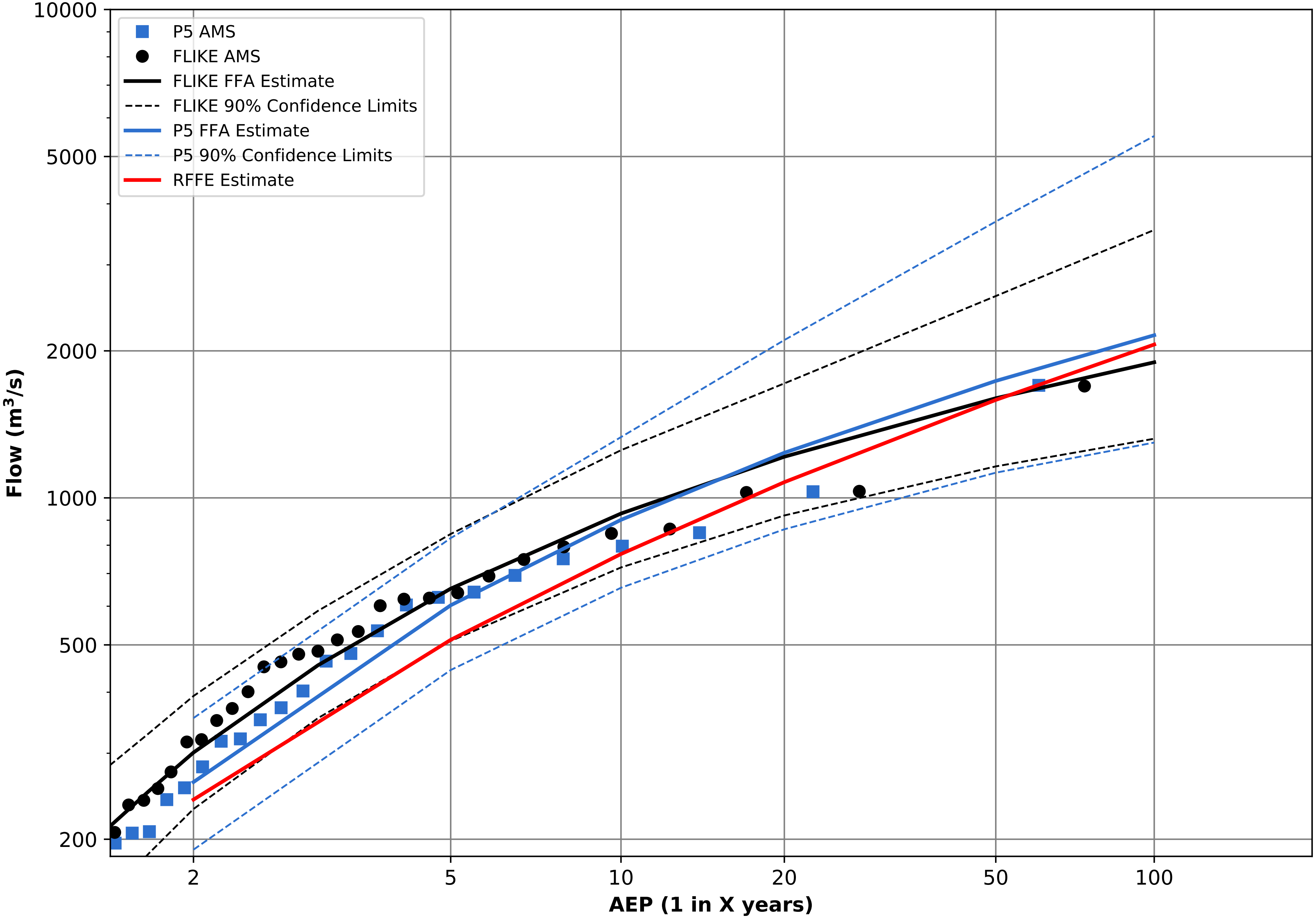

D/S BUNNOO R JUNCTION - 207013 [H33]
FFA VARIANTS

APPENDIX A108

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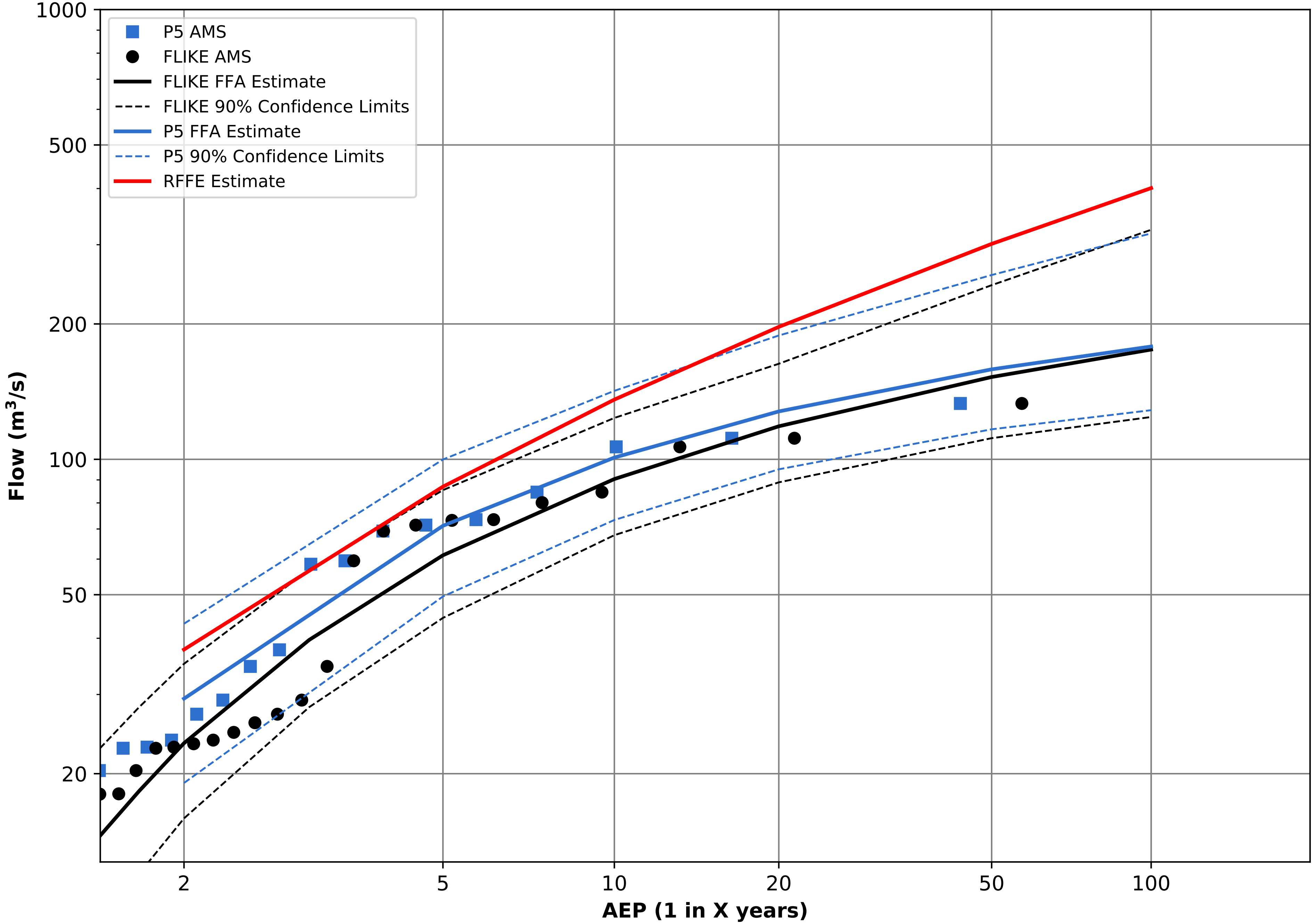

ABERMALA - 206034 [I1]

FFA VARIANTS

APPENDIX A109

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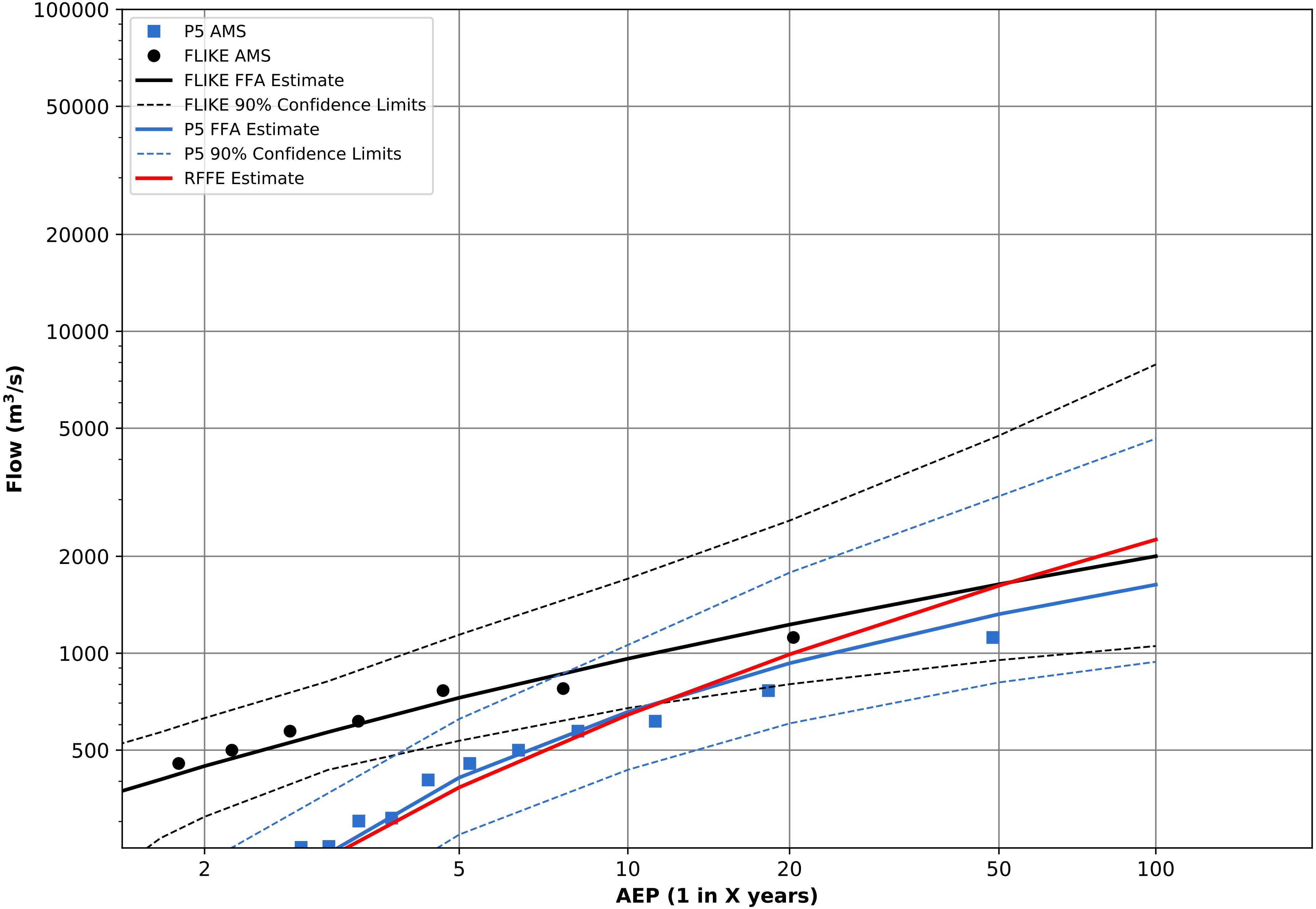

FINE FLOWER - 204067 [I2]

FFA VARIANTS

APPENDIX A110

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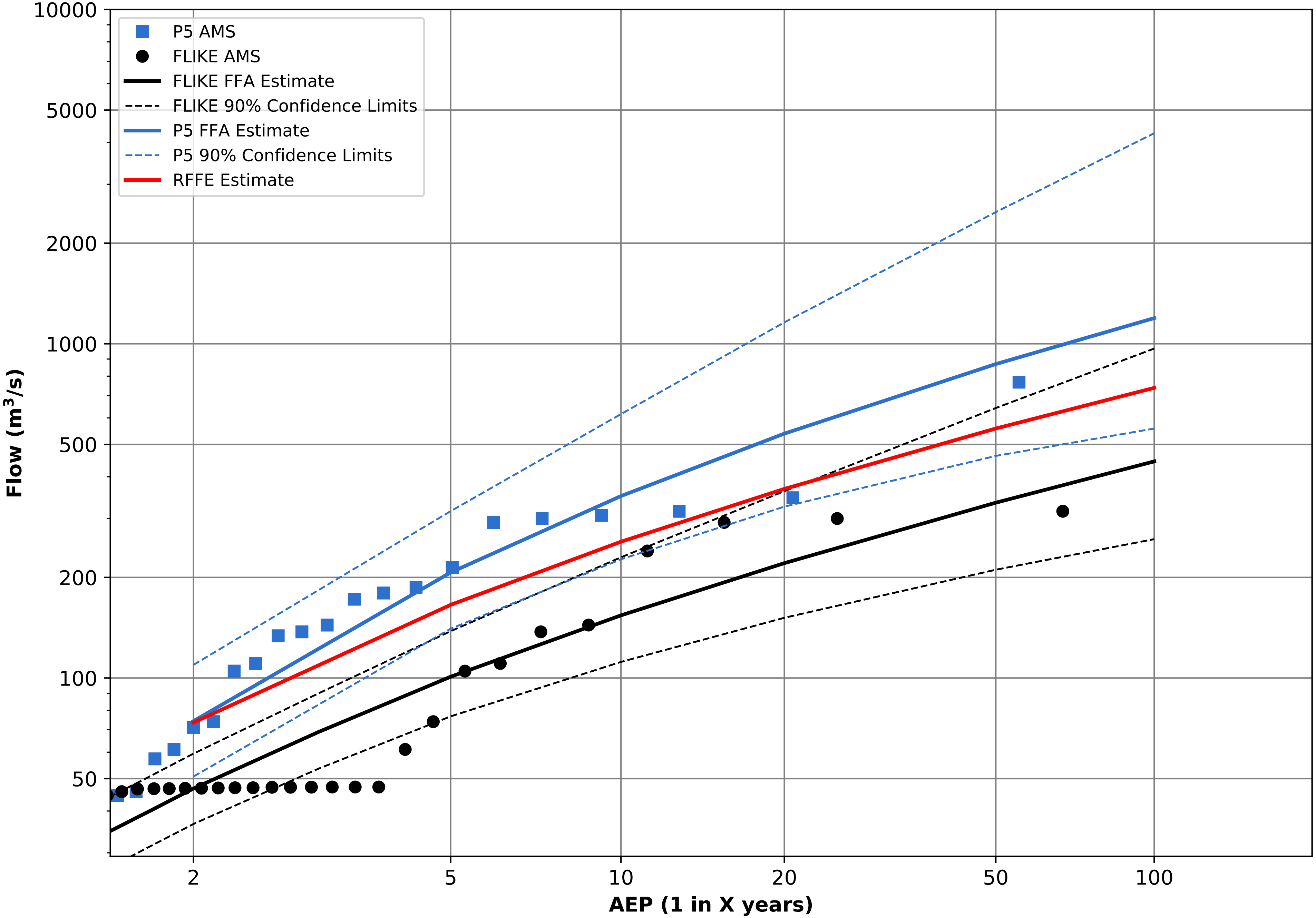
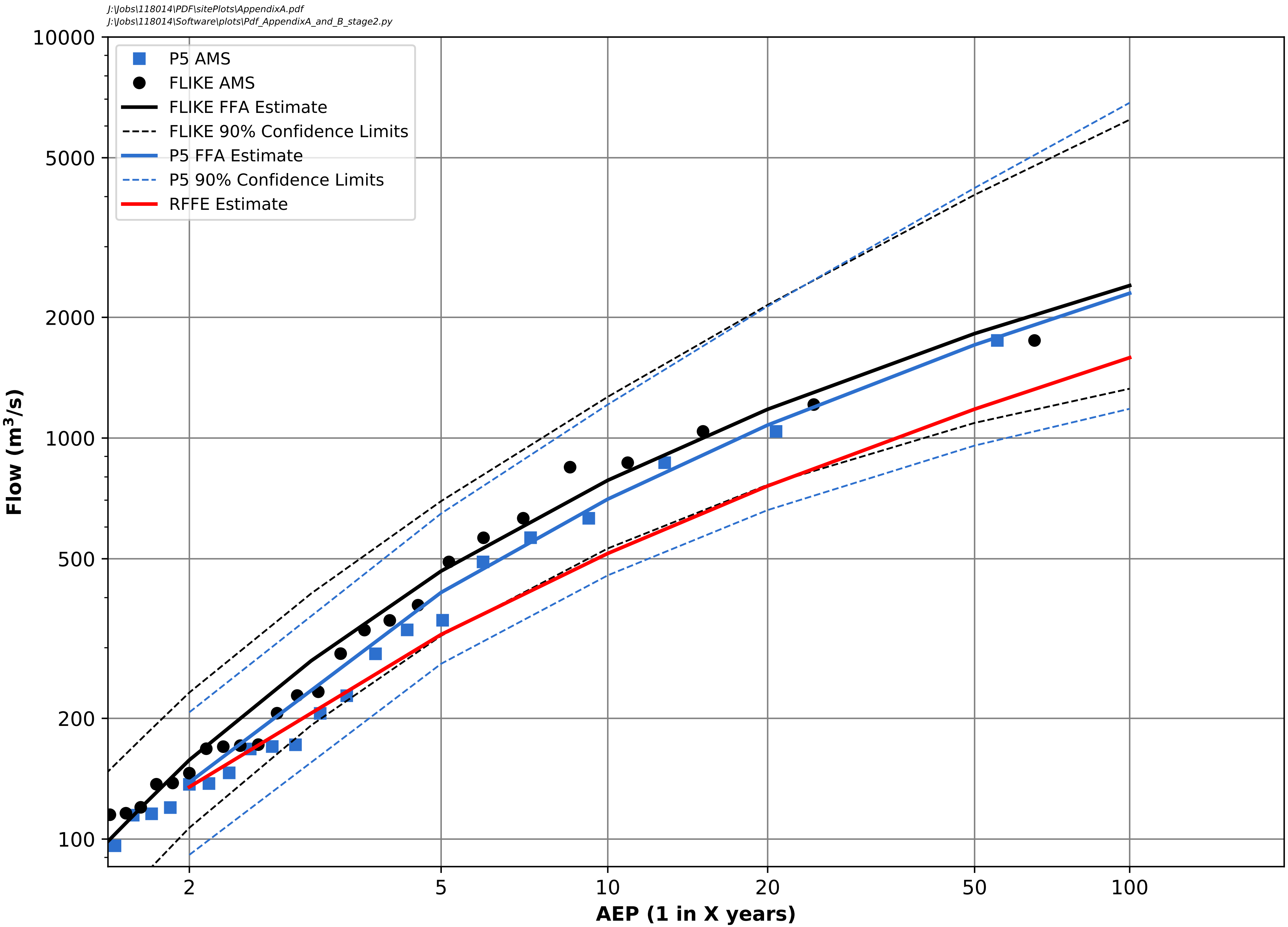


APPENDIX A111

FFA VARIANTS

JEOGLA - 206001 [I3]



BILLYRIMBA - 204033 [I4]
FFA VARIANTS
APPENDIX A112

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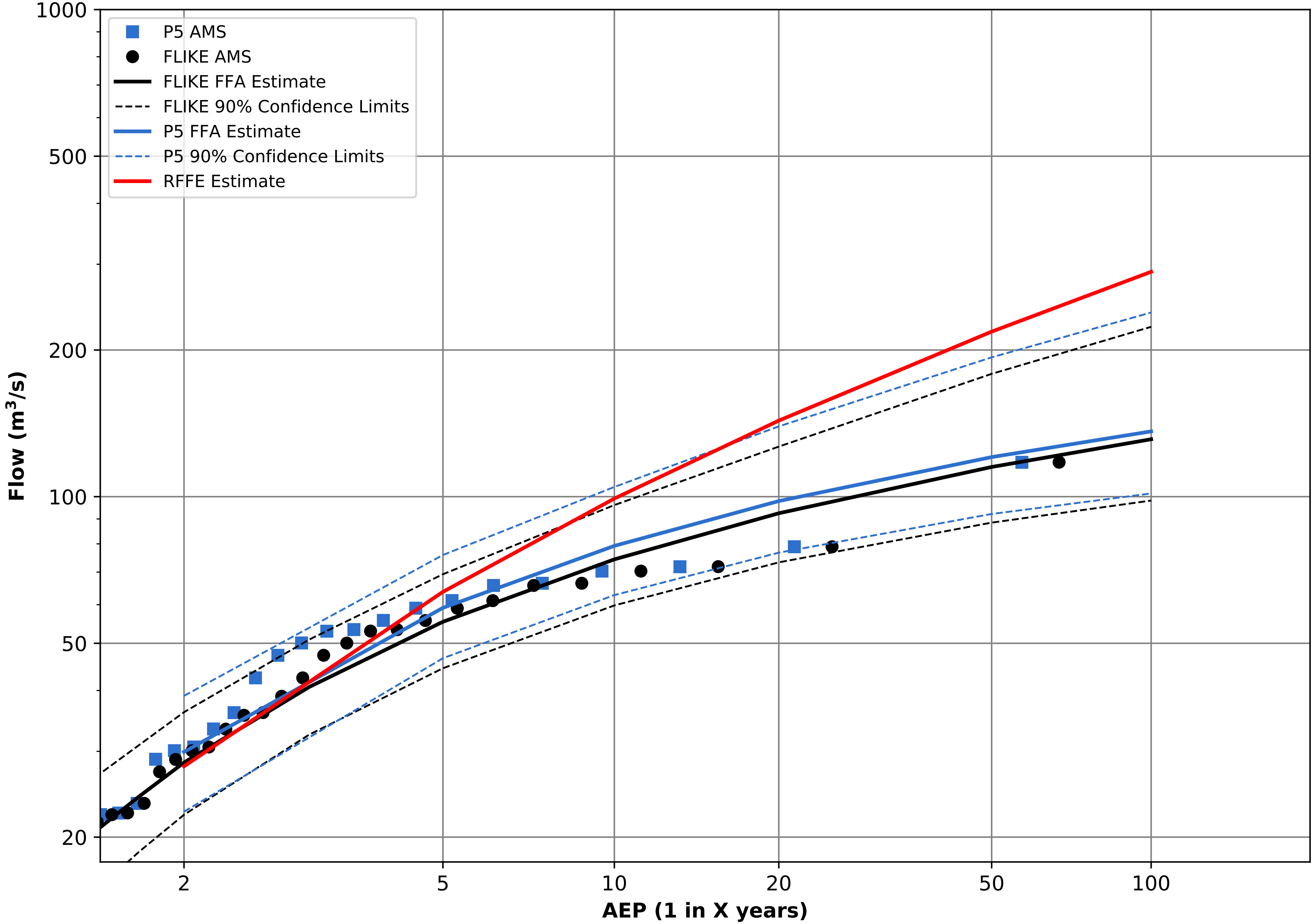

ABERFOYLE - 204030 [I5]
FFA VARIANTS
APPENDIX A113

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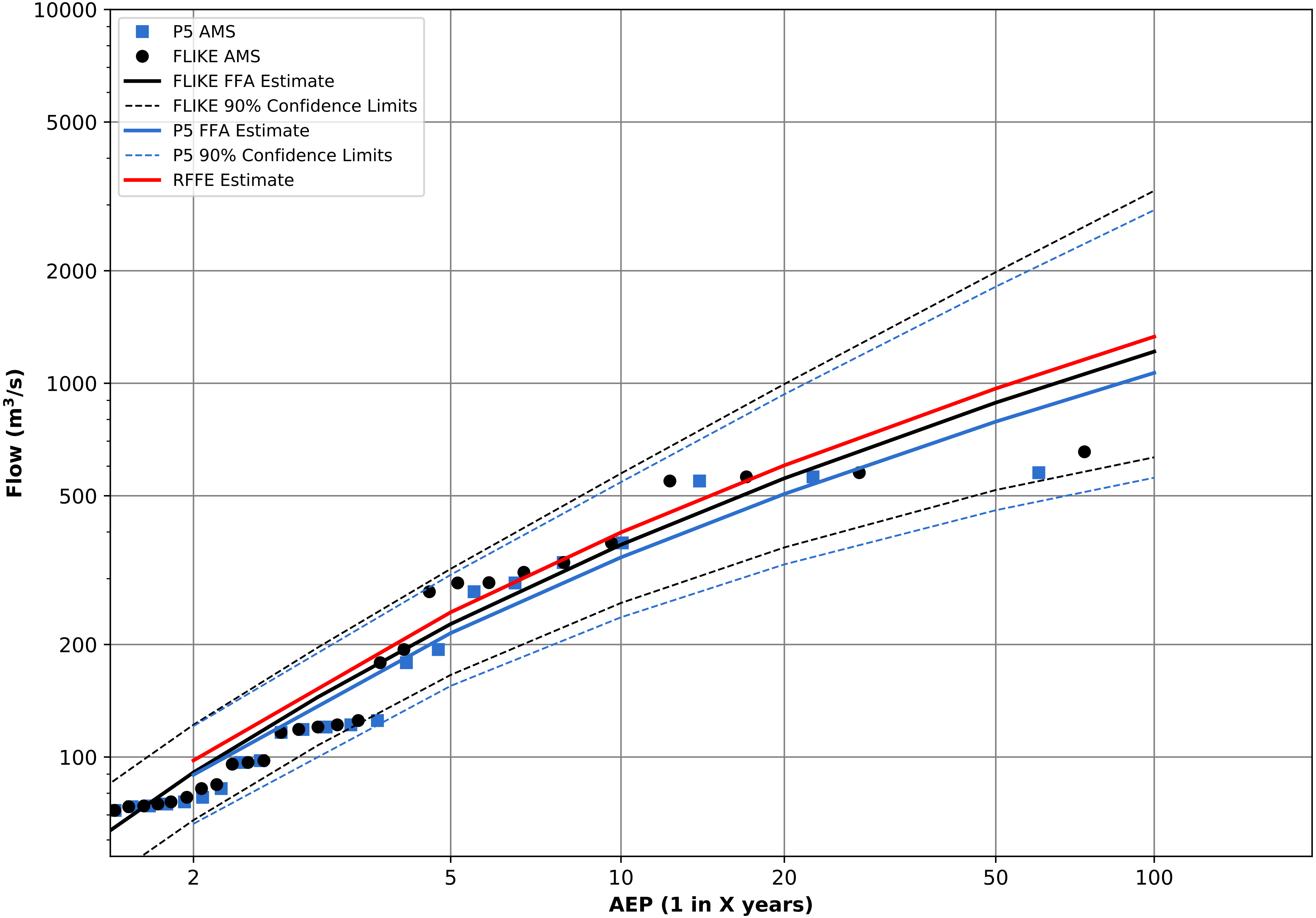

GIBRALTAR RANGE - 204056 [I6]
FFA VARIANTS

APPENDIX A114

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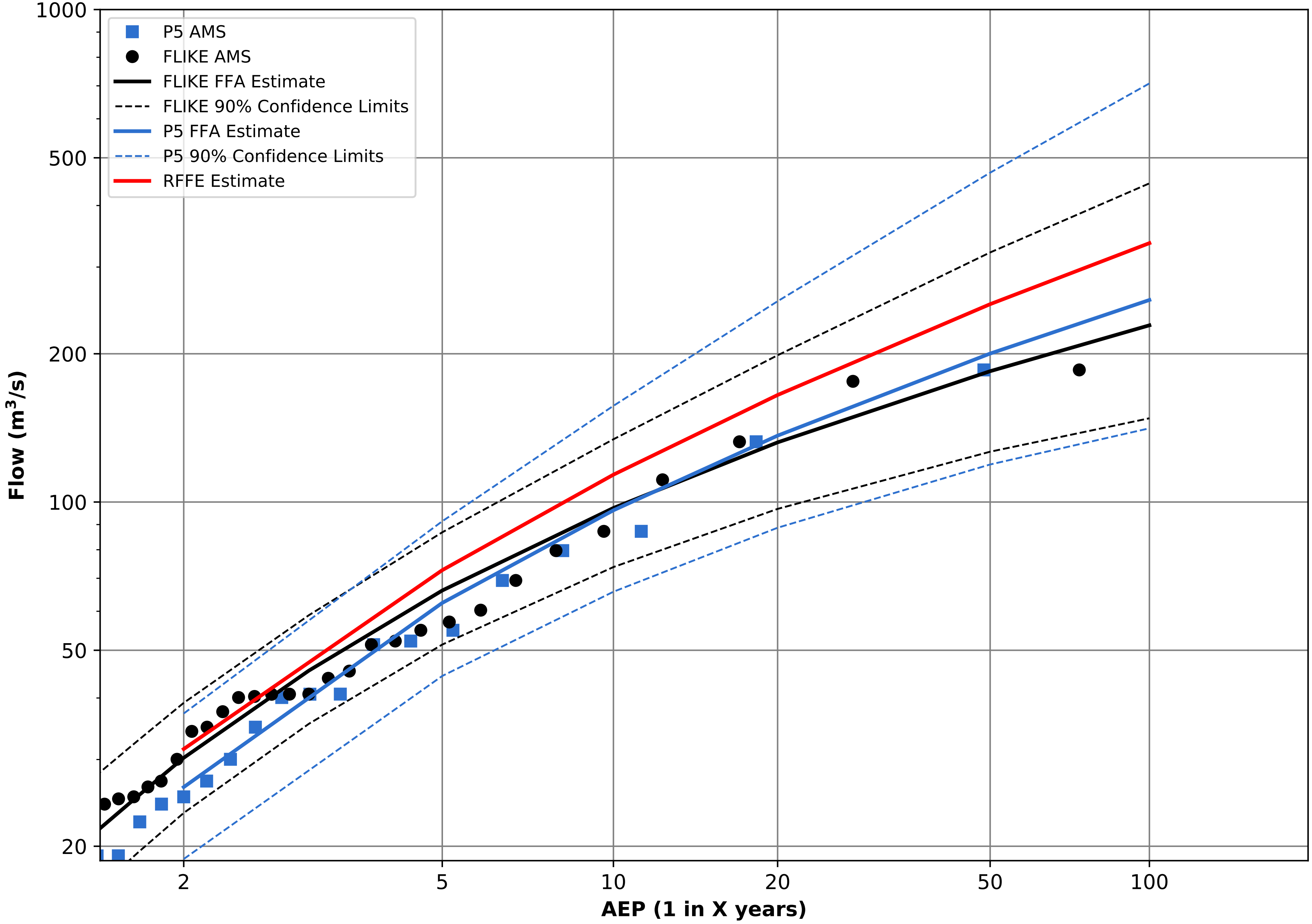
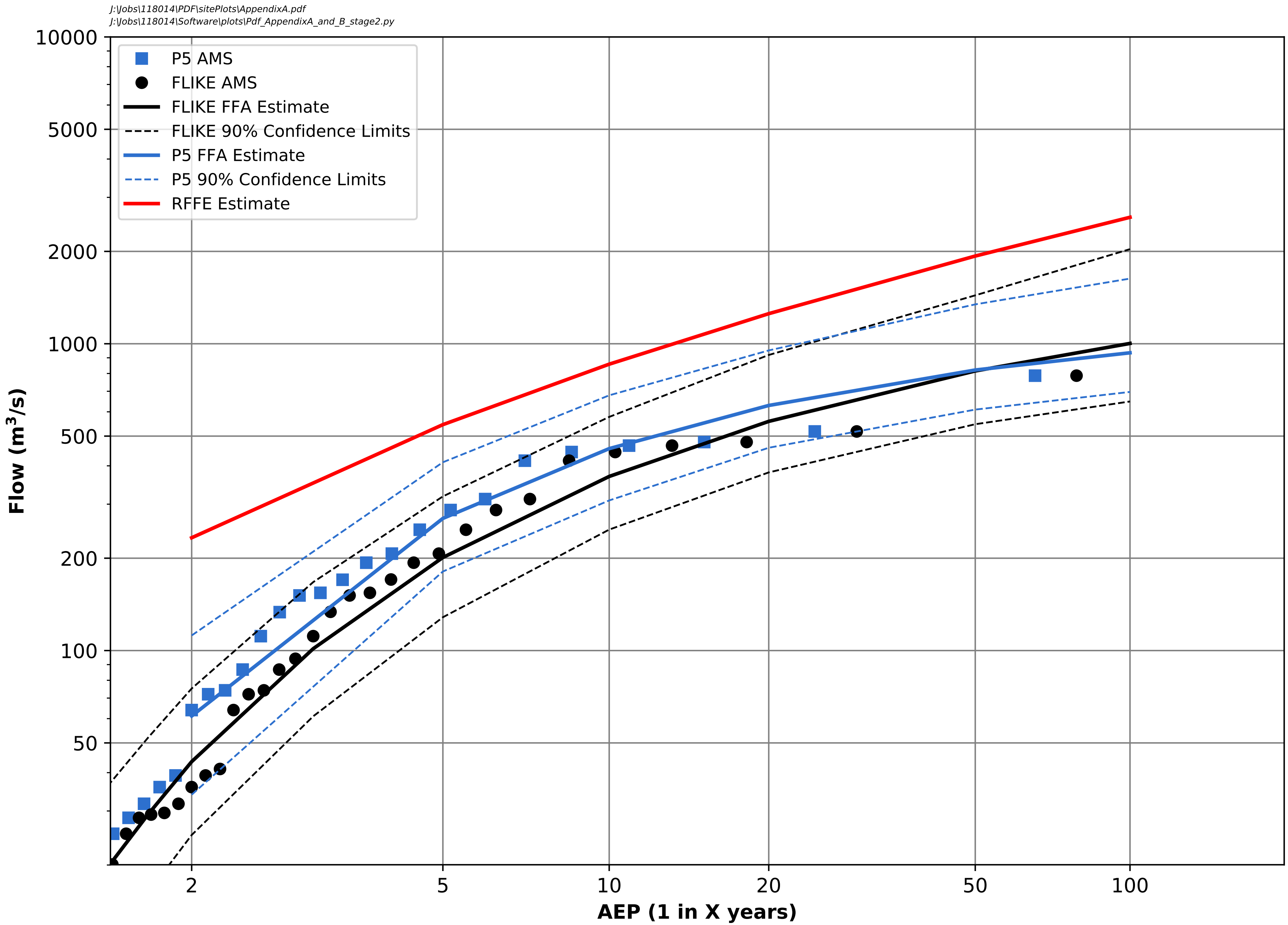


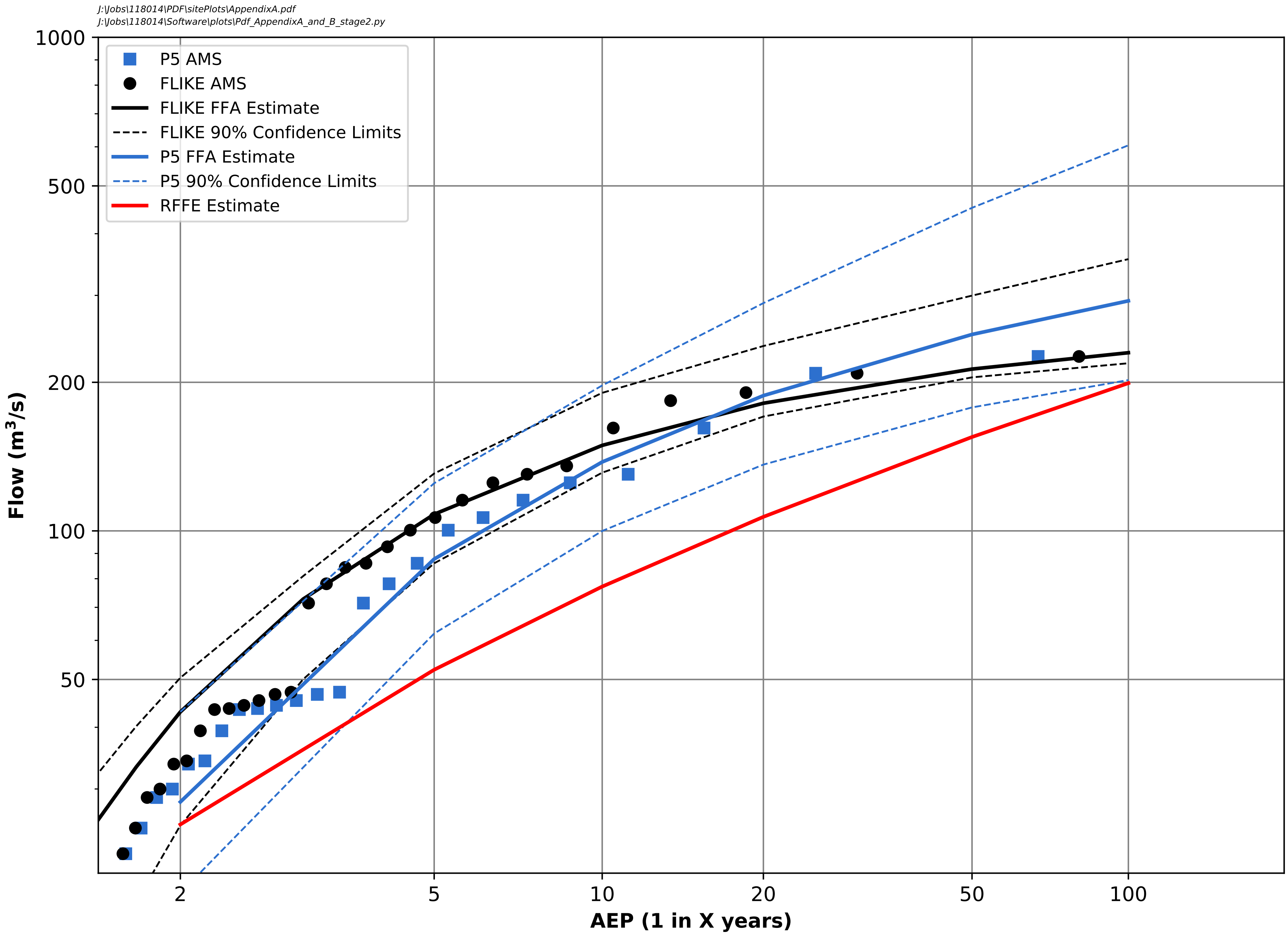
APPENDIX A115
FFA VARIANTS
EBOR - 204008 [I7]



NEAR DANGAR FALLS - 206025 [I8]

FFA VARIANTS

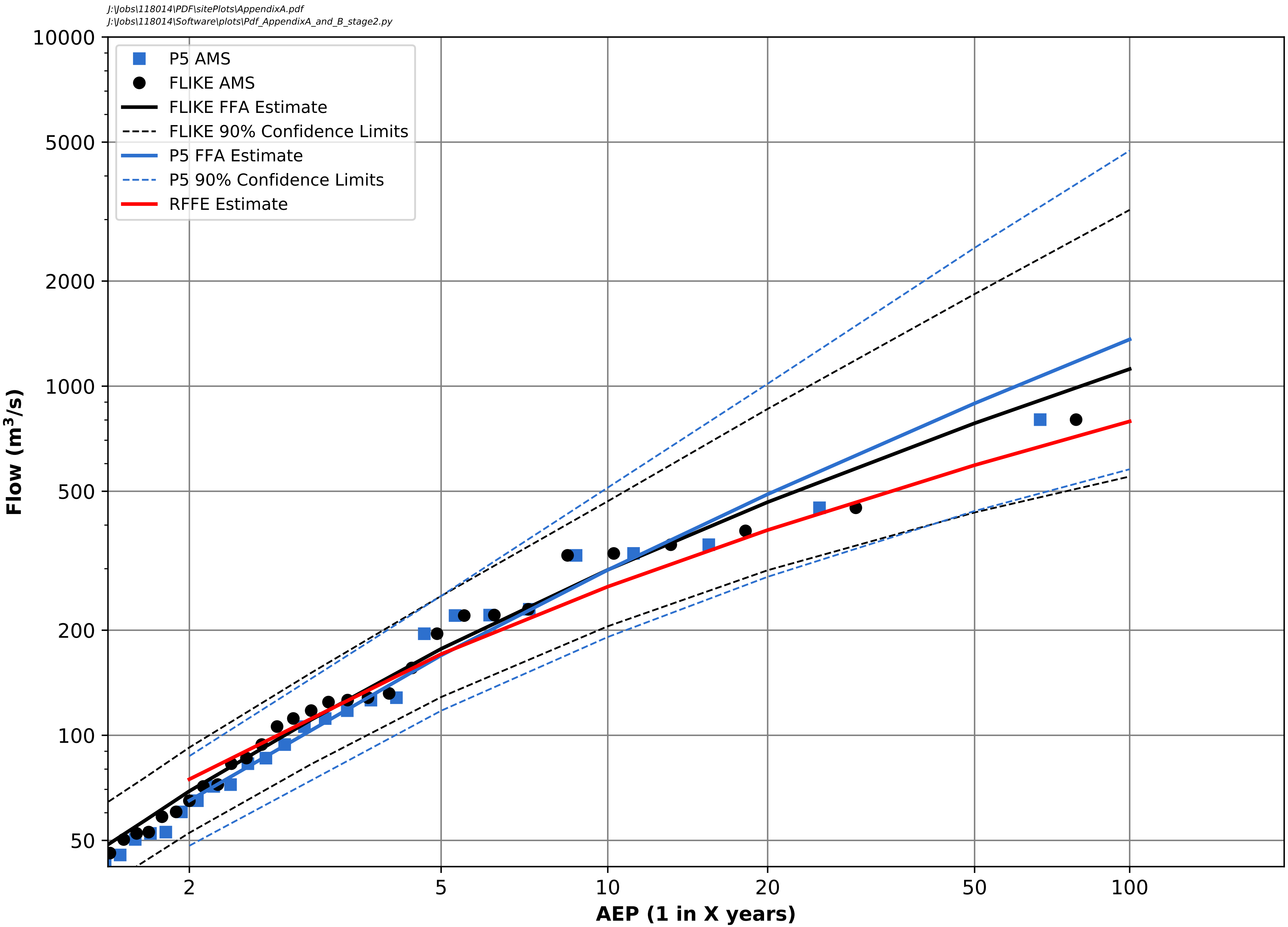
APPENDIX A116



CLOUDS CK - 204037 [I9]

FFA VARIANTS

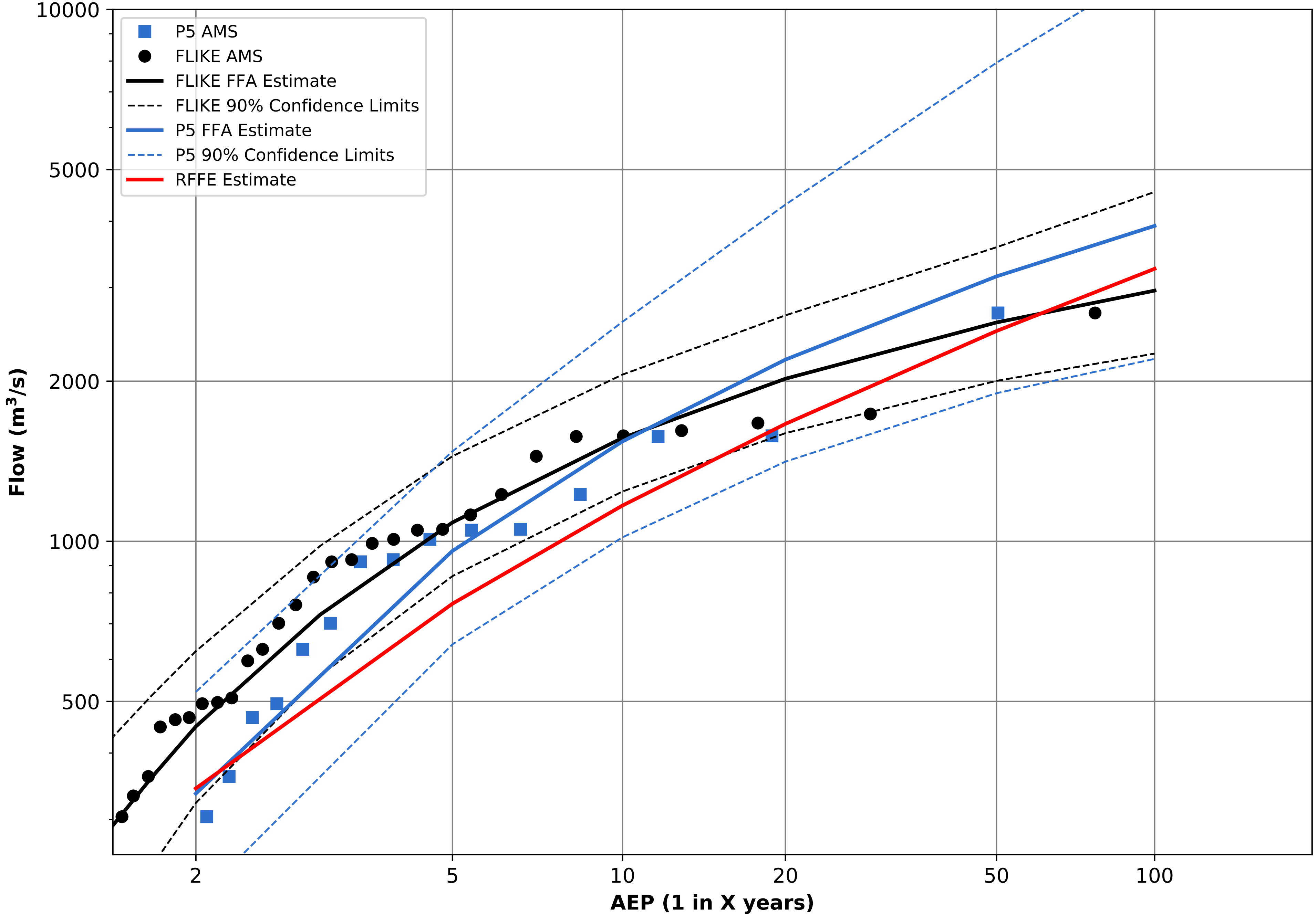
APPENDIX A117



APPENDIX A118

FFA VARIANTS

NEWTON BOYD - 204034 [110]



FFA VARIANTS
WIANGAREE - 203005 [I11]

APPENDIX A119

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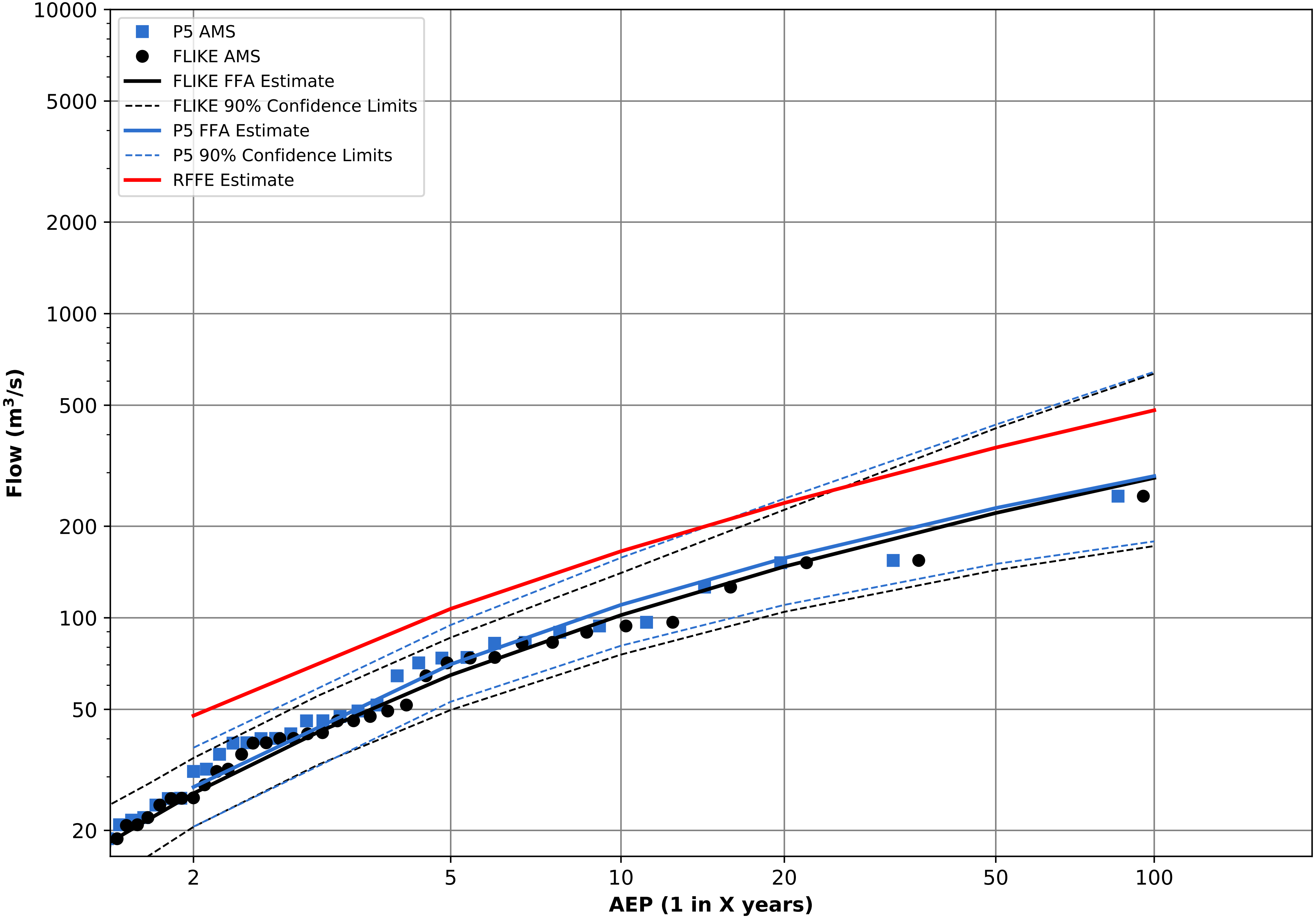

APPENDIX A120
FFA VARIANTS
BONALBO - 204043 [I12]

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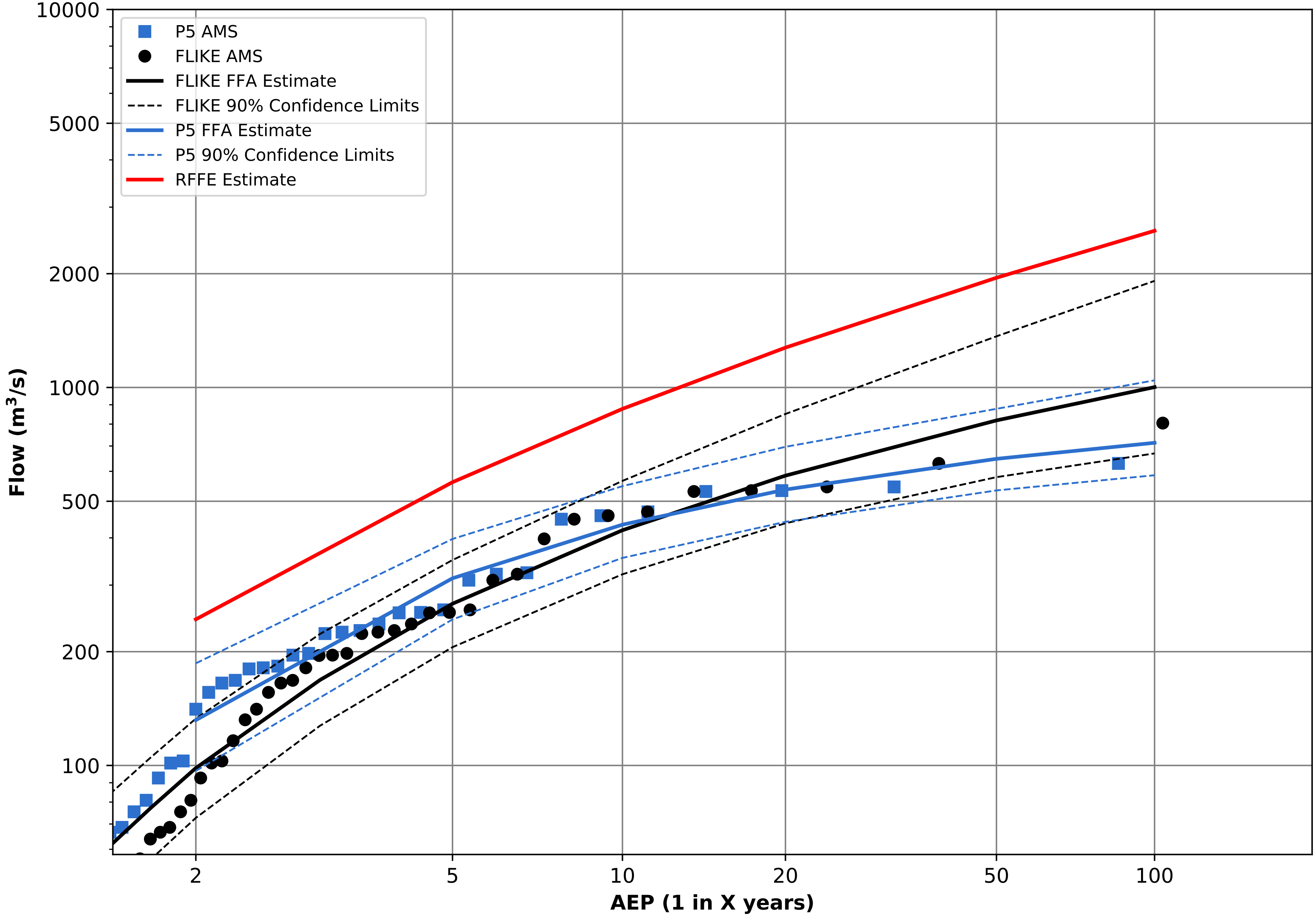
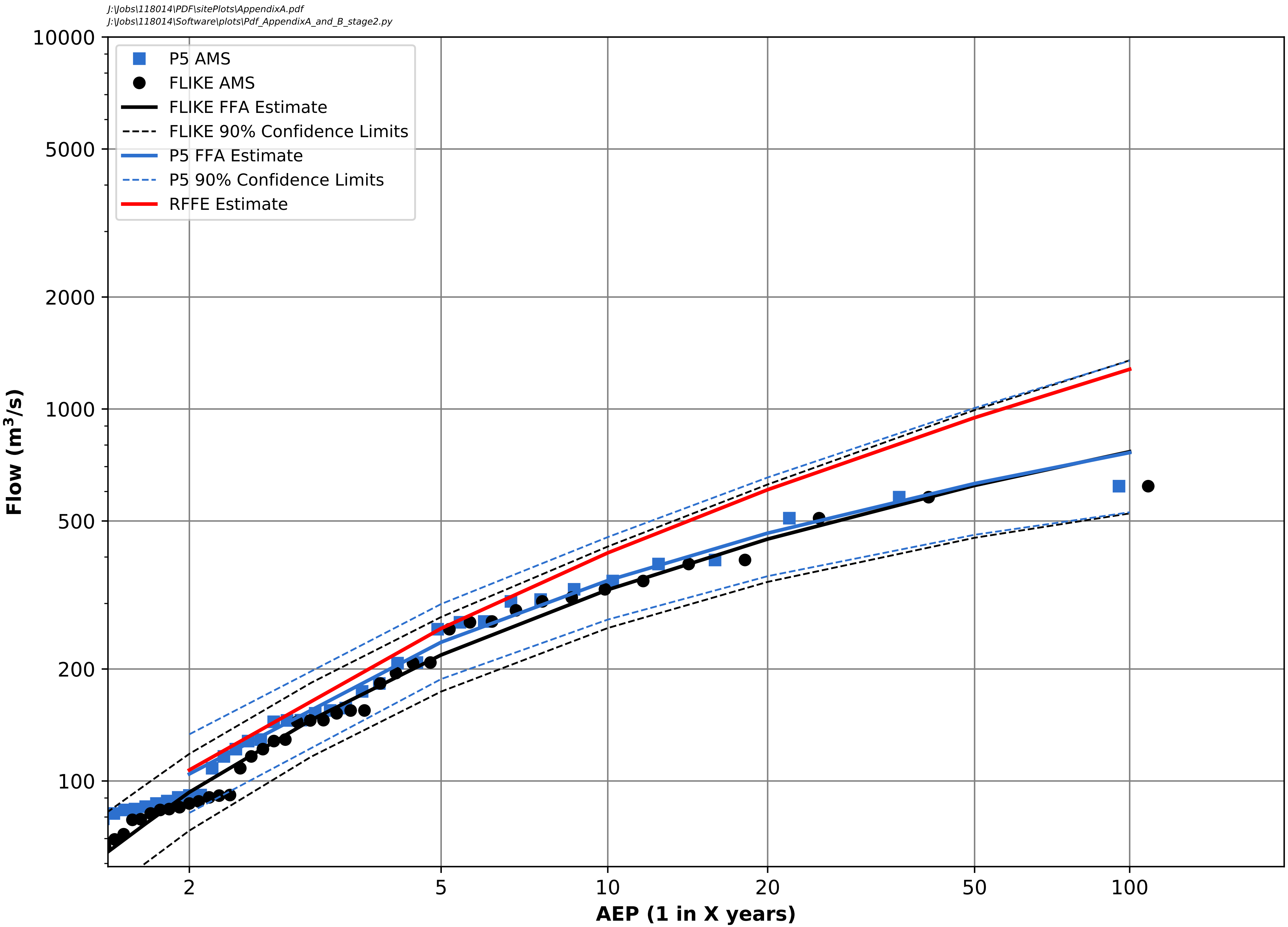


APSLEY FALLS - 206018 [I13]
FFA VARIANTS
APPENDIX A121



CONINSIDE - 206014 [I14]
FFA VARIANTS
APPENDIX A122

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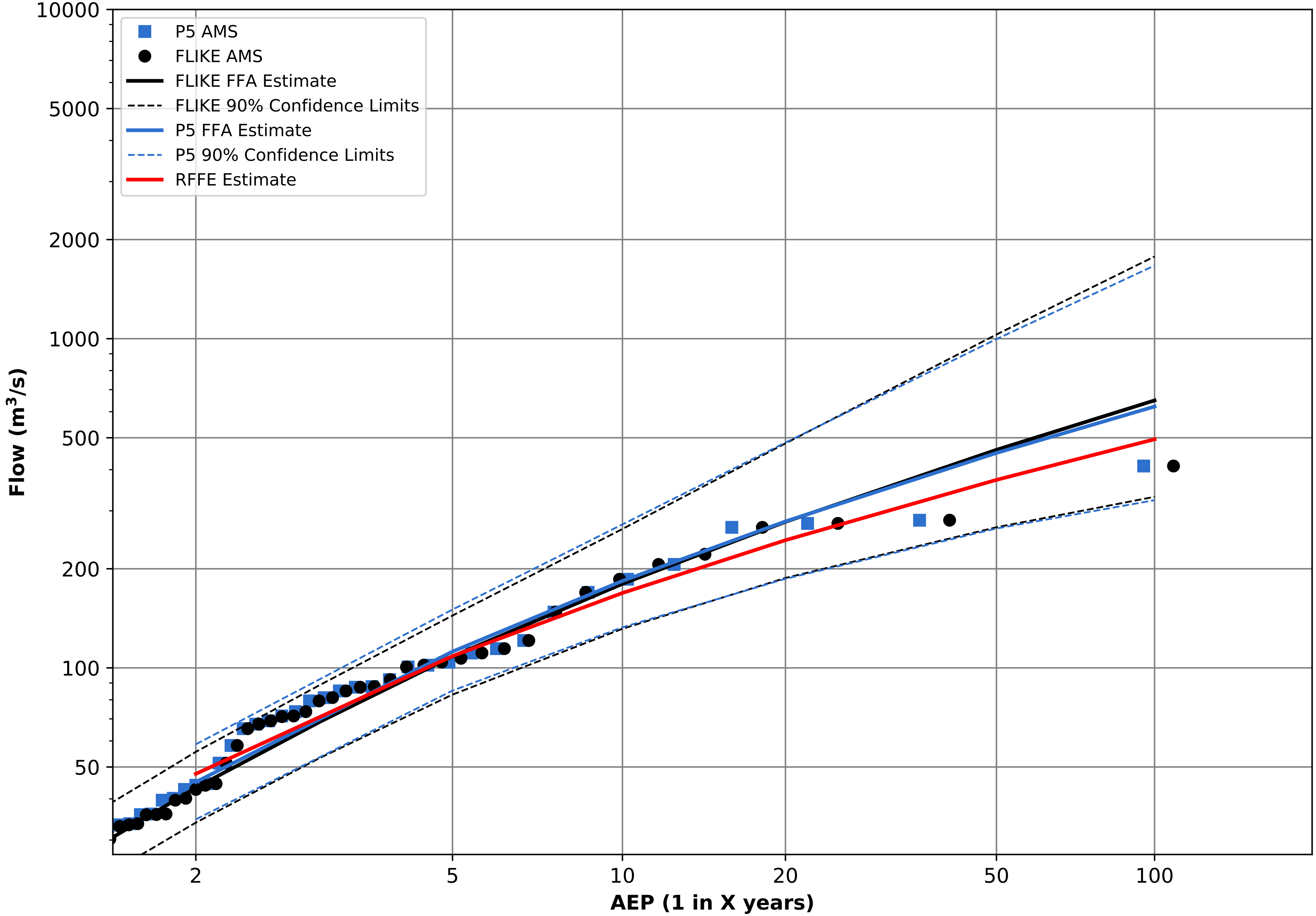

APPENDIX A123

FFA VARIANTS

TIA - 206009 [I15]

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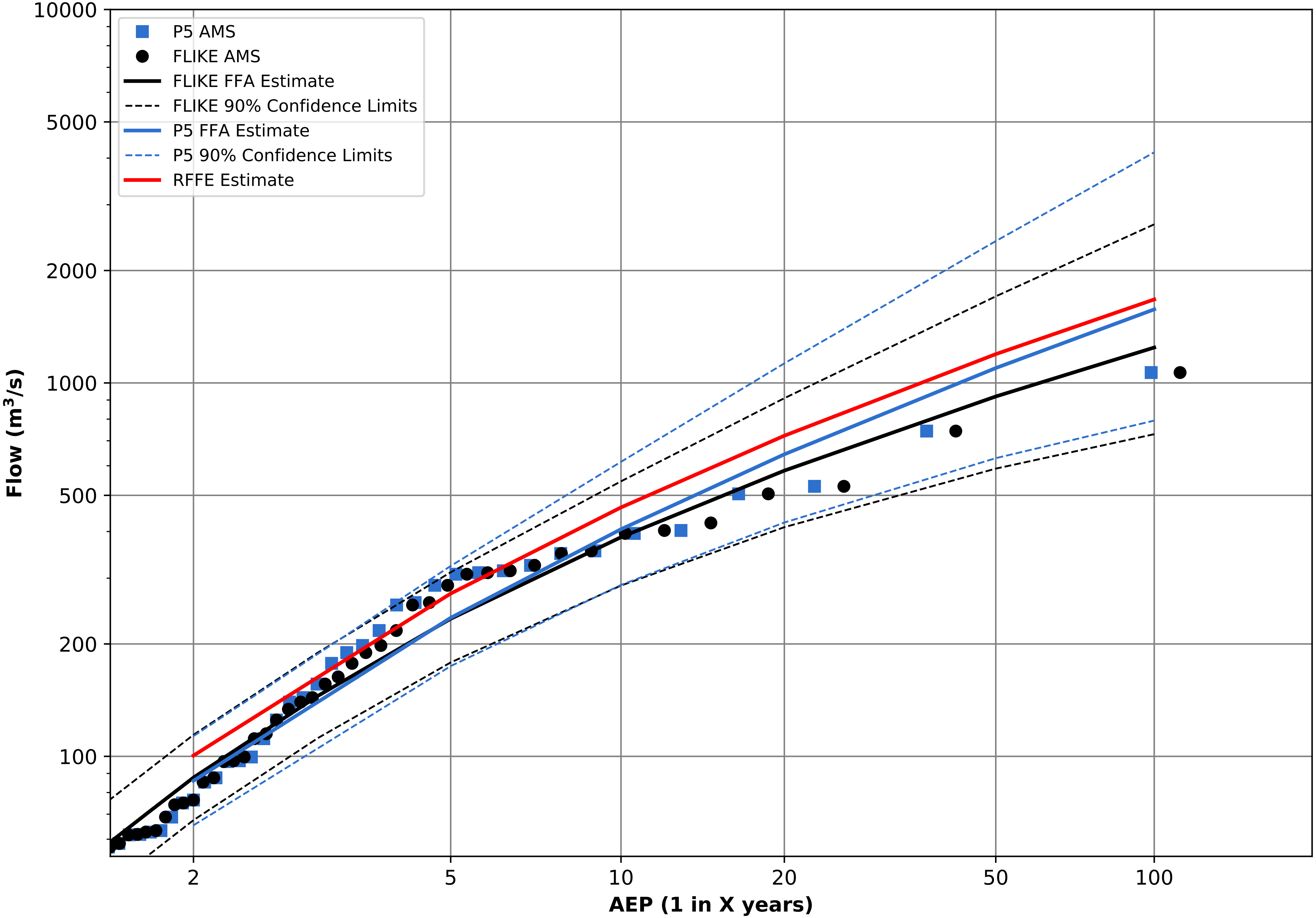

SANDY HILL(BELOW SNAKE CRE) - 204036 [116]

FFA VARIANTS

APPENDIX A124

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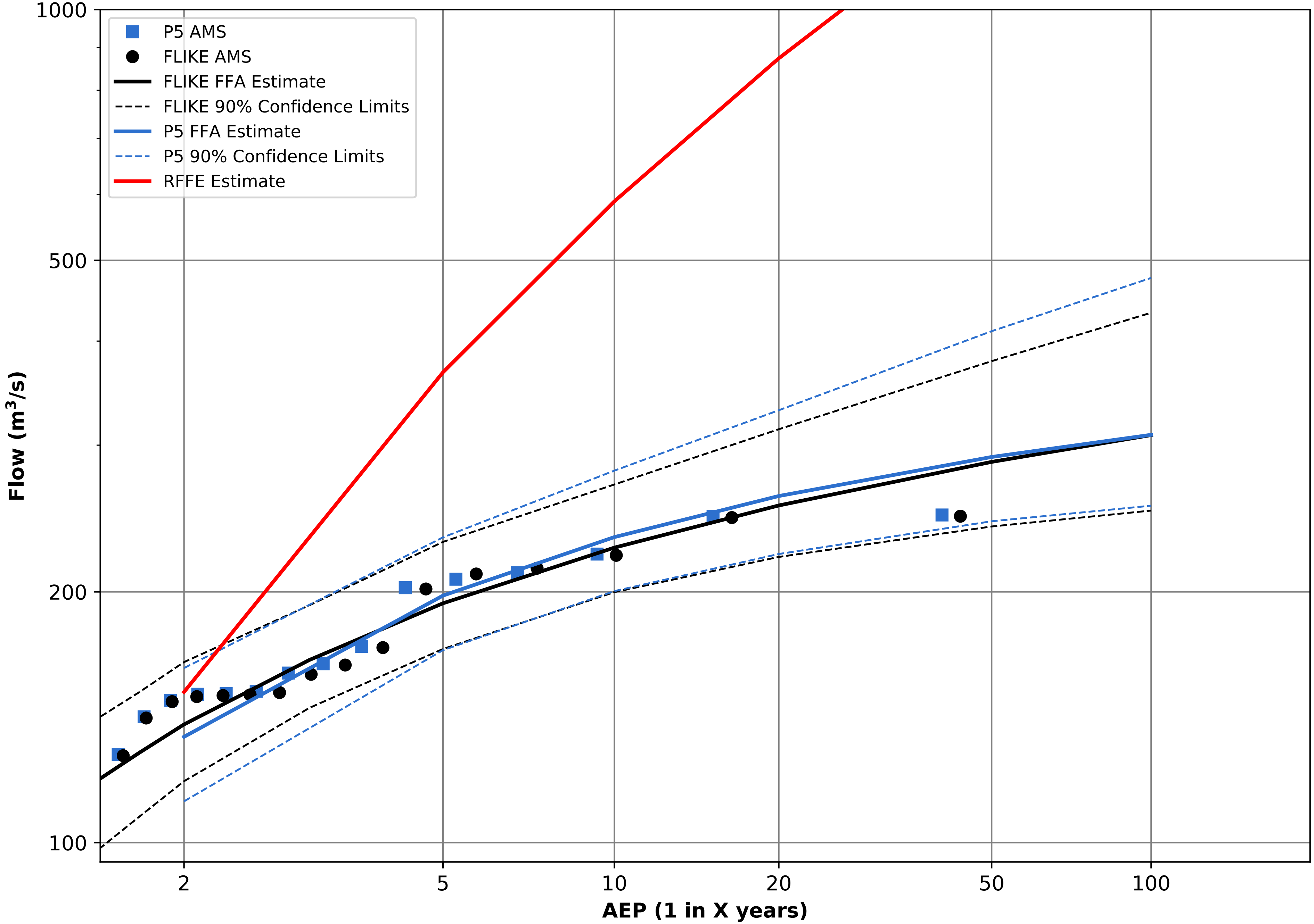

GLENIFFER BR - 205014 [I17]
FFA VARIANTS
APPENDIX A125

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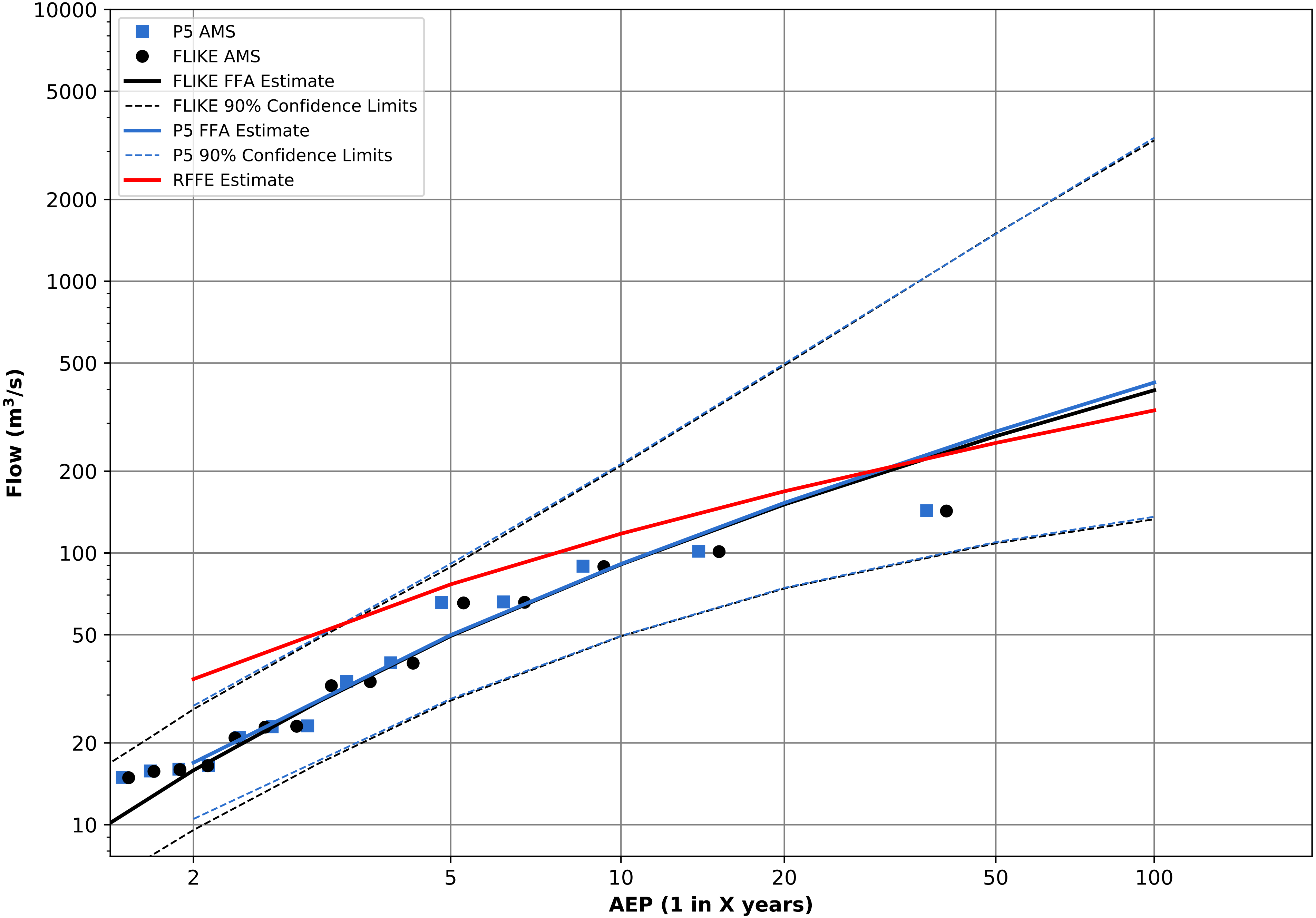

WOOLGOOLGA - 205007 [18]

FFA VARIANTS

APPENDIX A126

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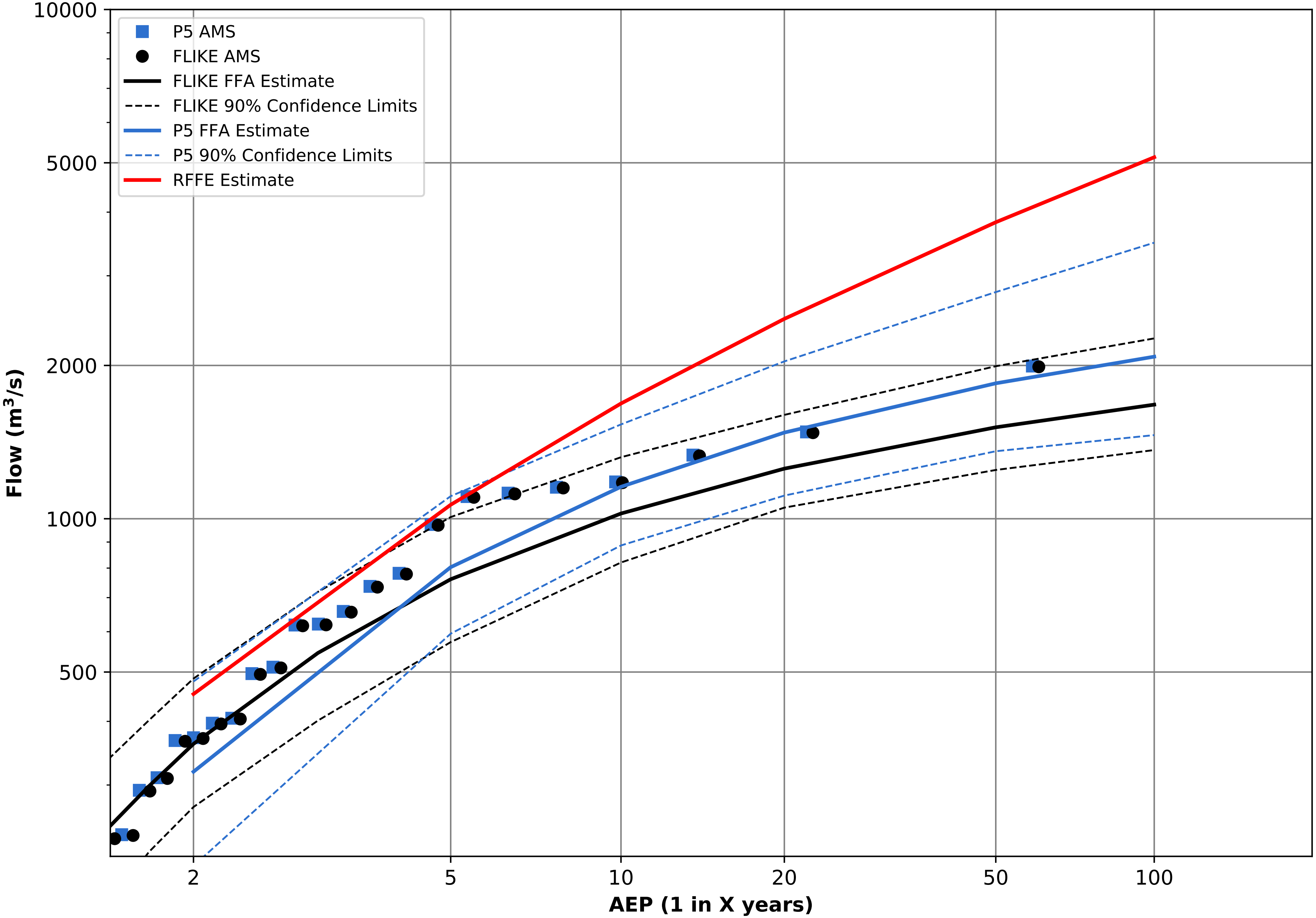

BOWRAVILLE - 205006 [I19]
FFA VARIANTS
APPENDIX A127

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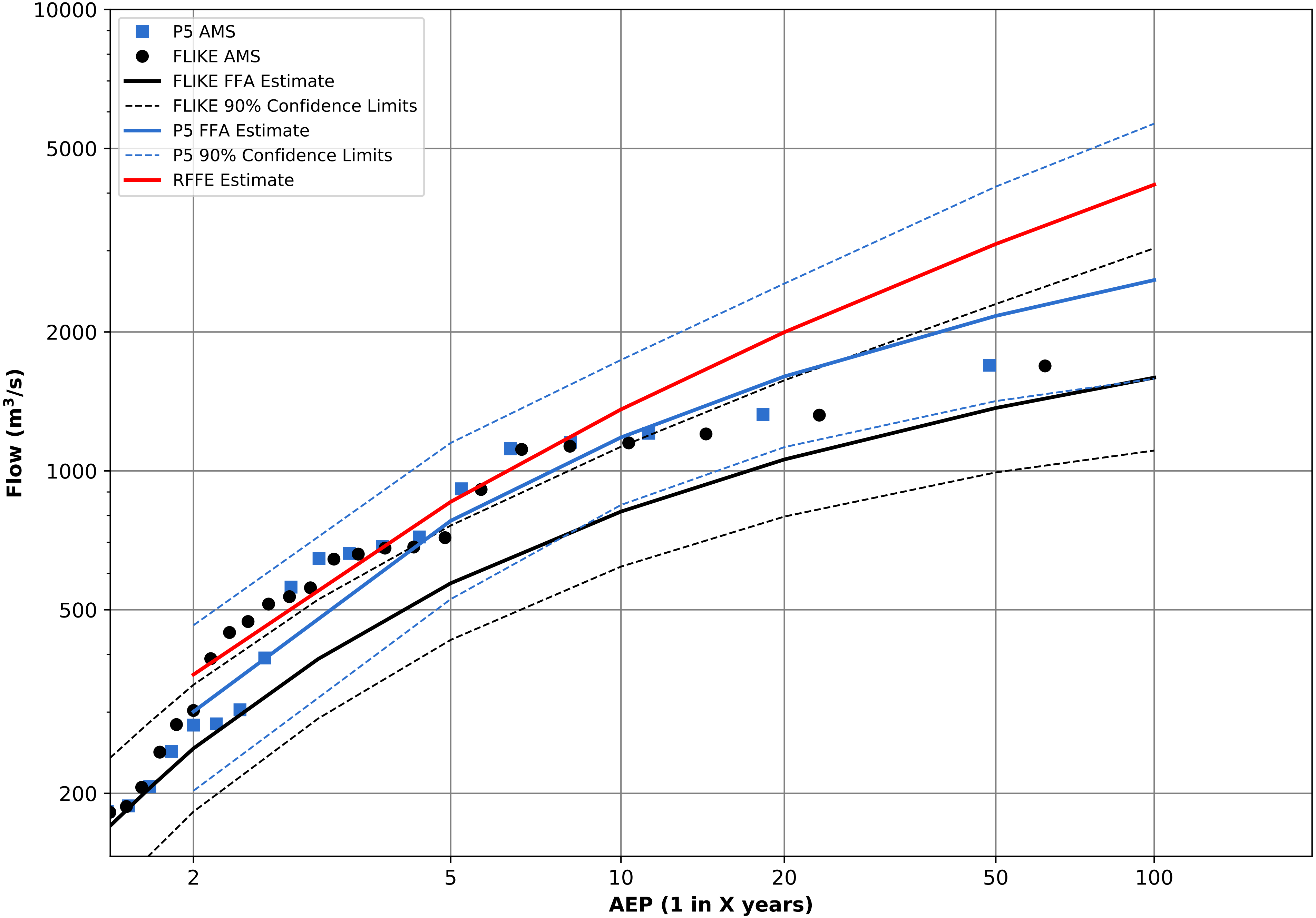
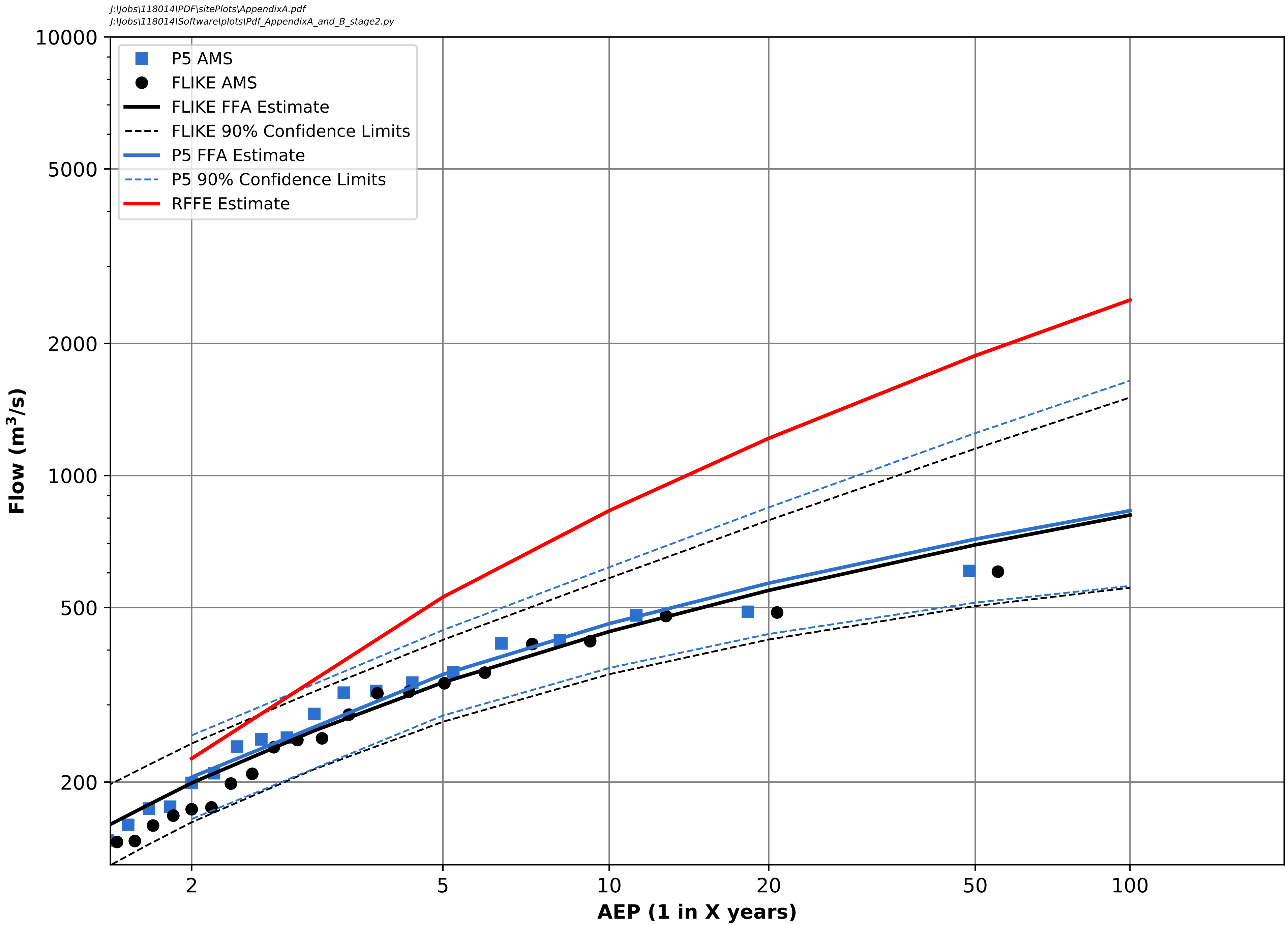


THORA - 205002 [I20]
FFA VARIANTS
APPENDIX A128



BOBO NURSERY - 204026 [I21]
FFA VARIANTS

APPENDIX A129

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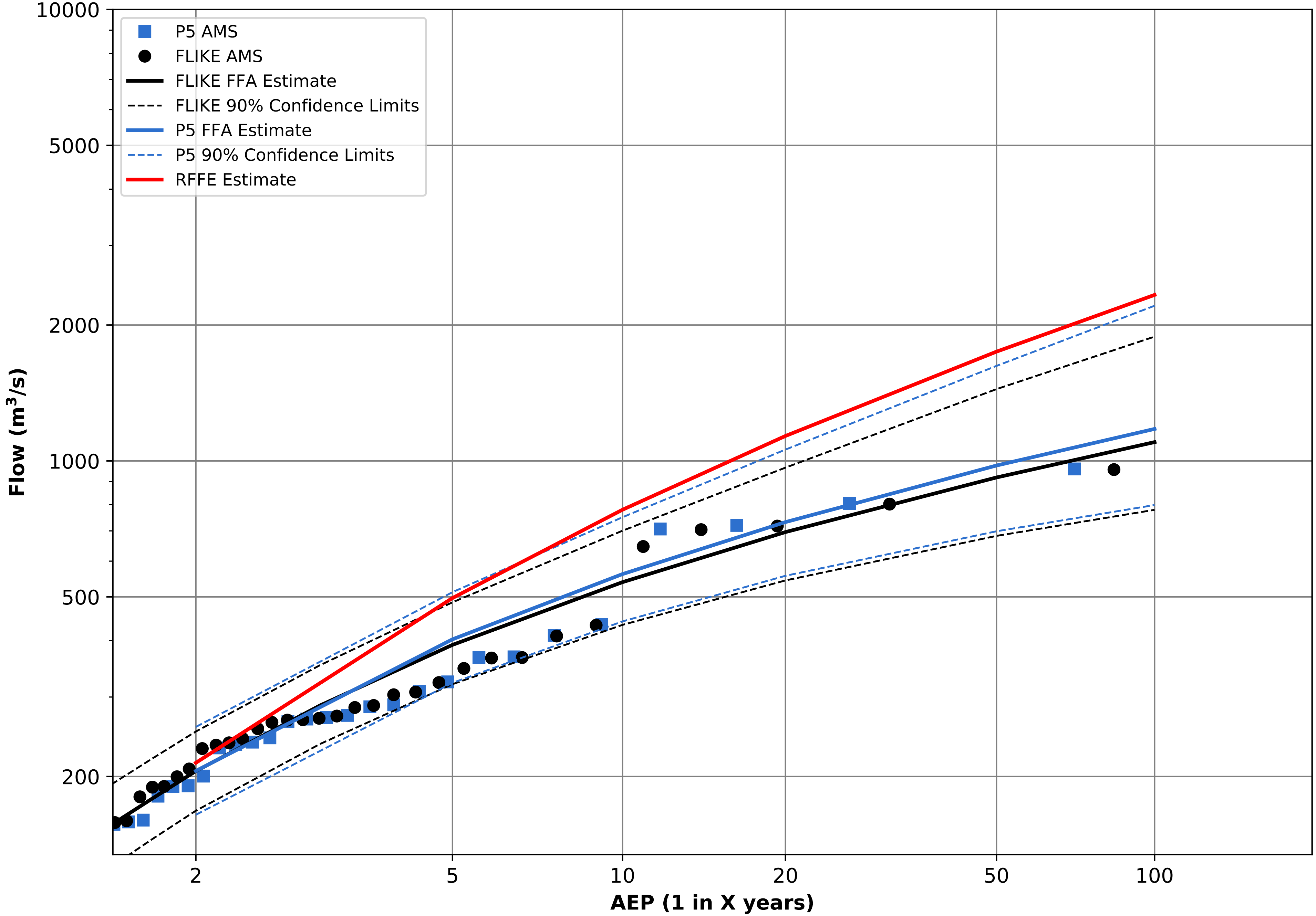

KARANGI - 204025 [I22]
FFA VARIANTS
APPENDIX A130

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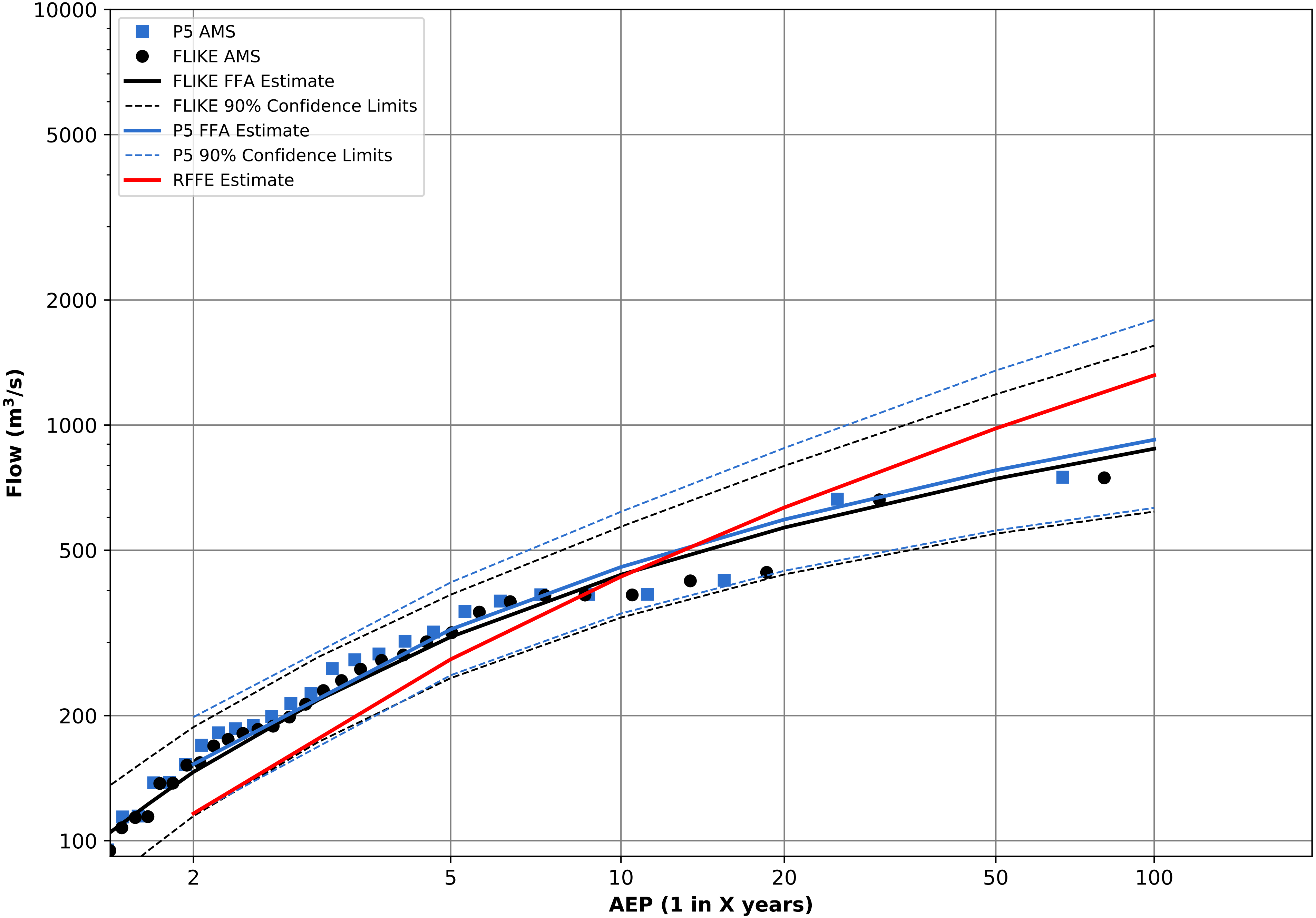

DORRIGO NO.2 & NO.3 - 204017 [I23]
FFA VARIANTS
APPENDIX A131

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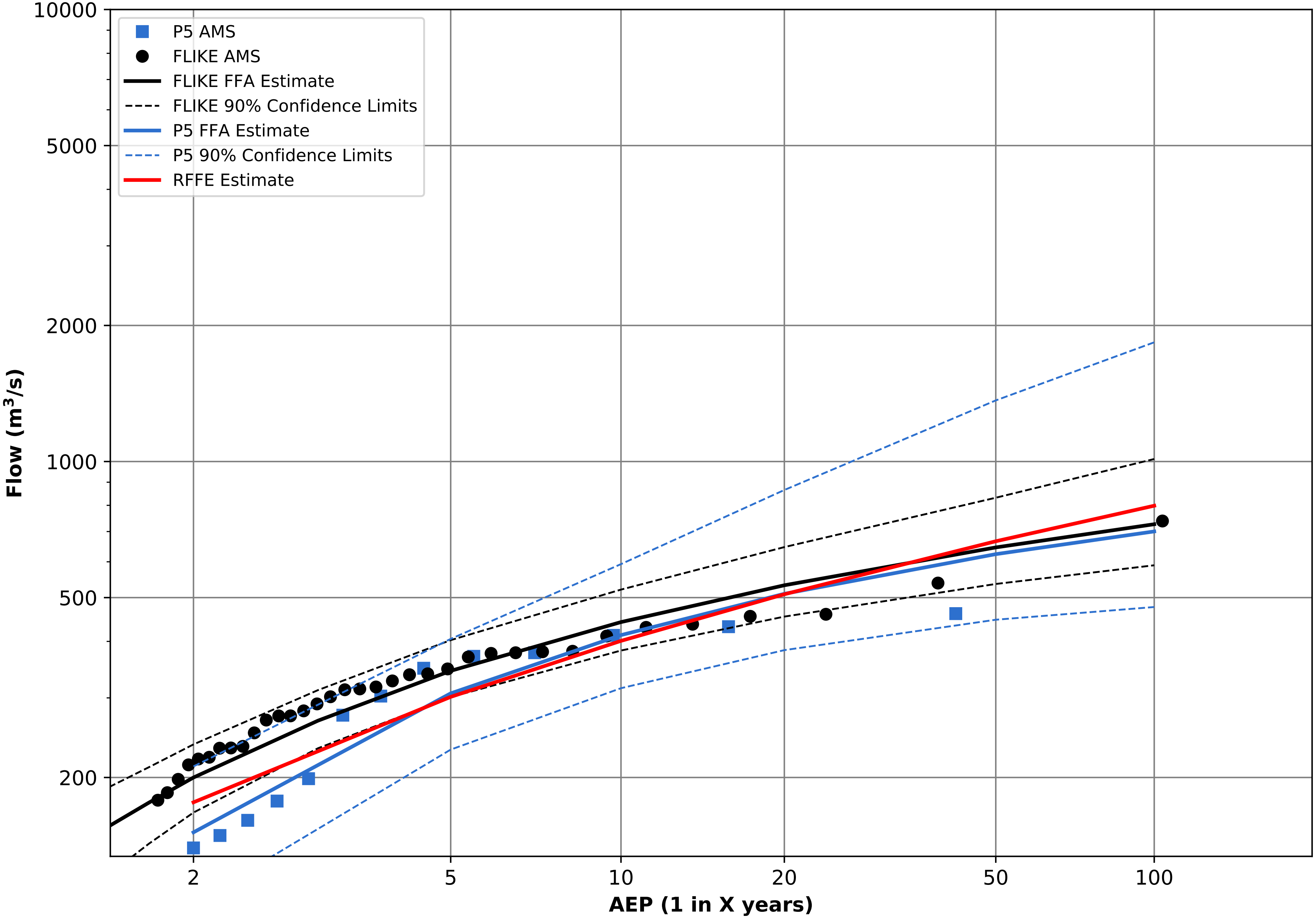

ELTHAM - 203014 [I24]
FFA VARIANTS
APPENDIX A132

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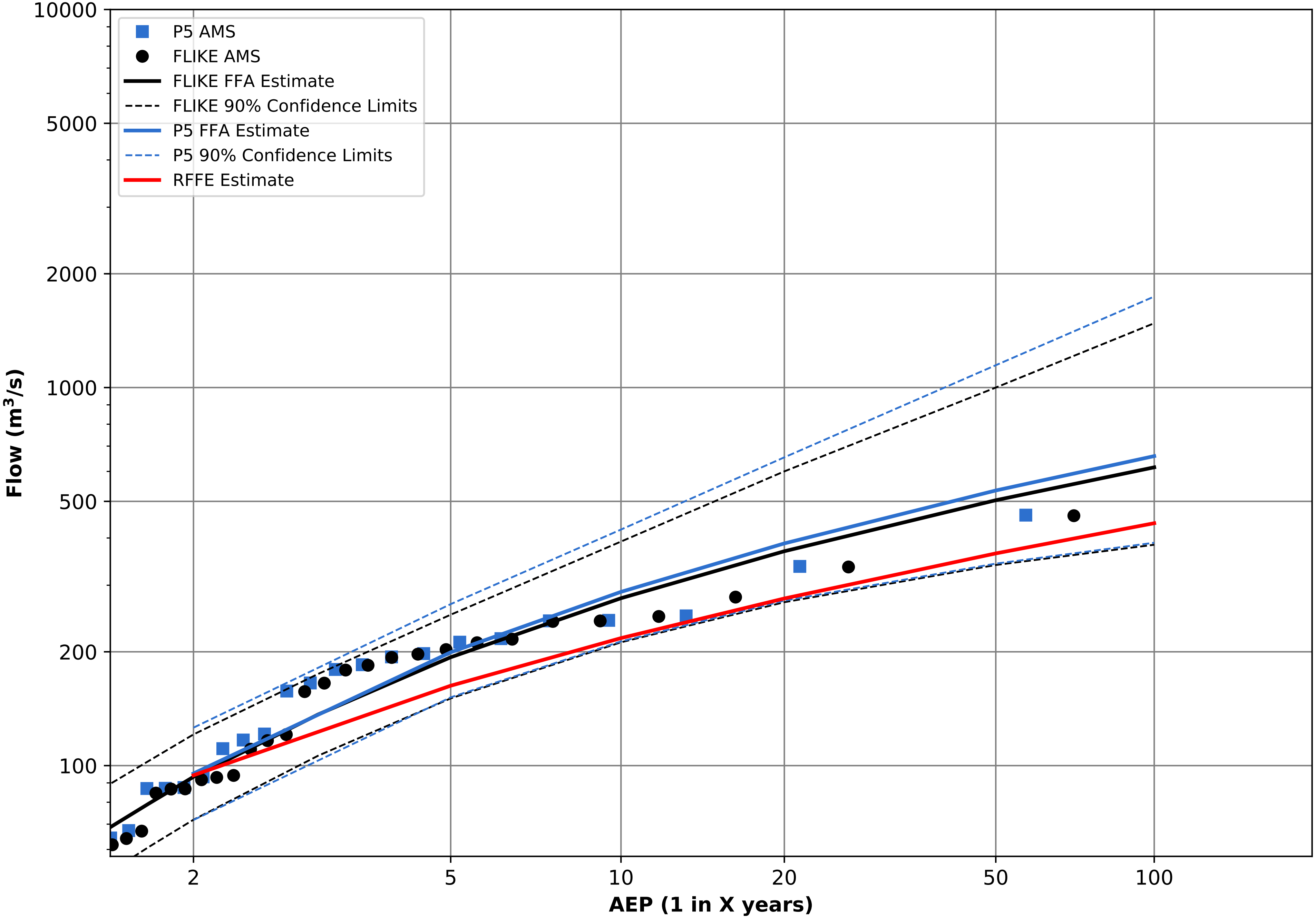
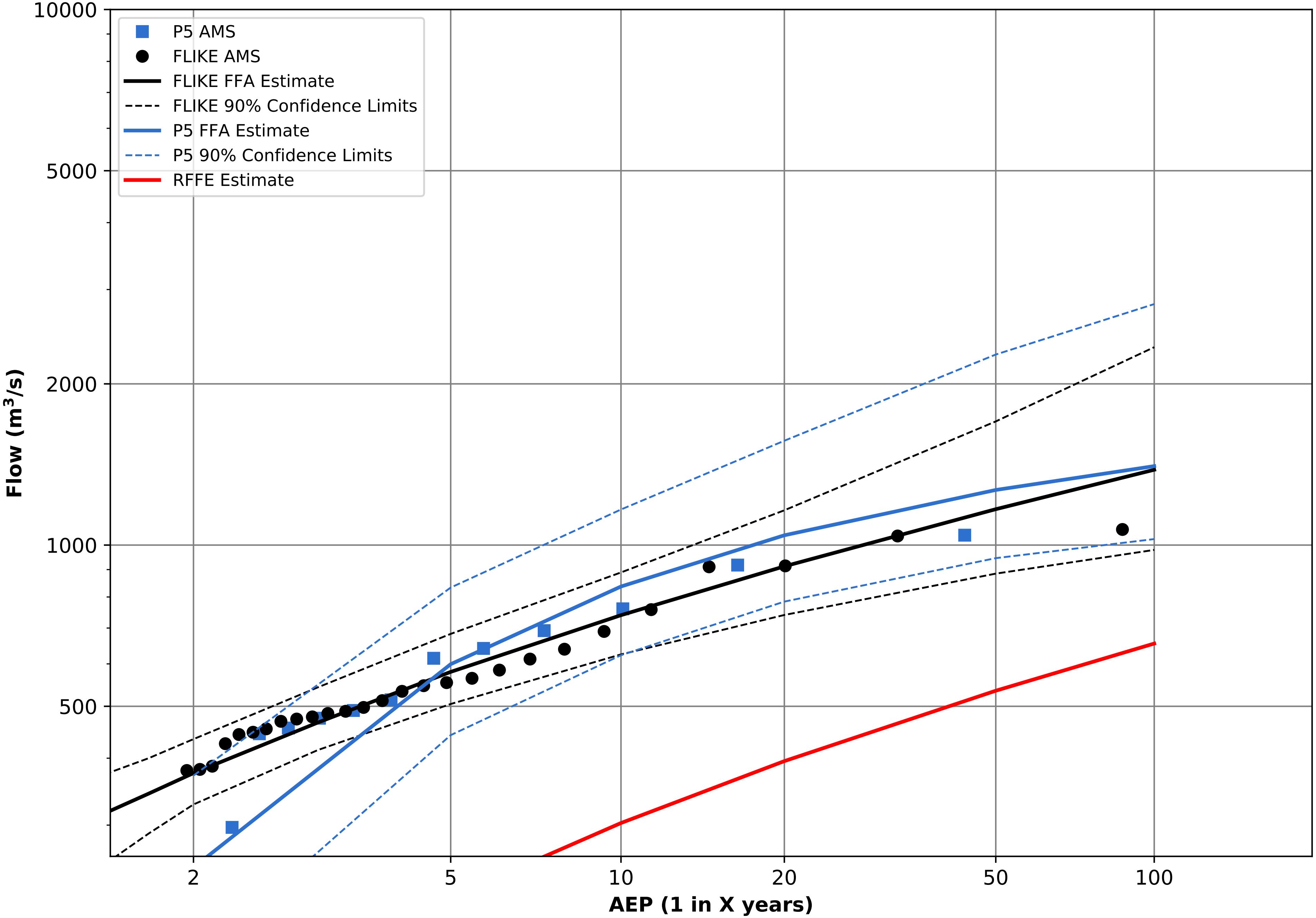
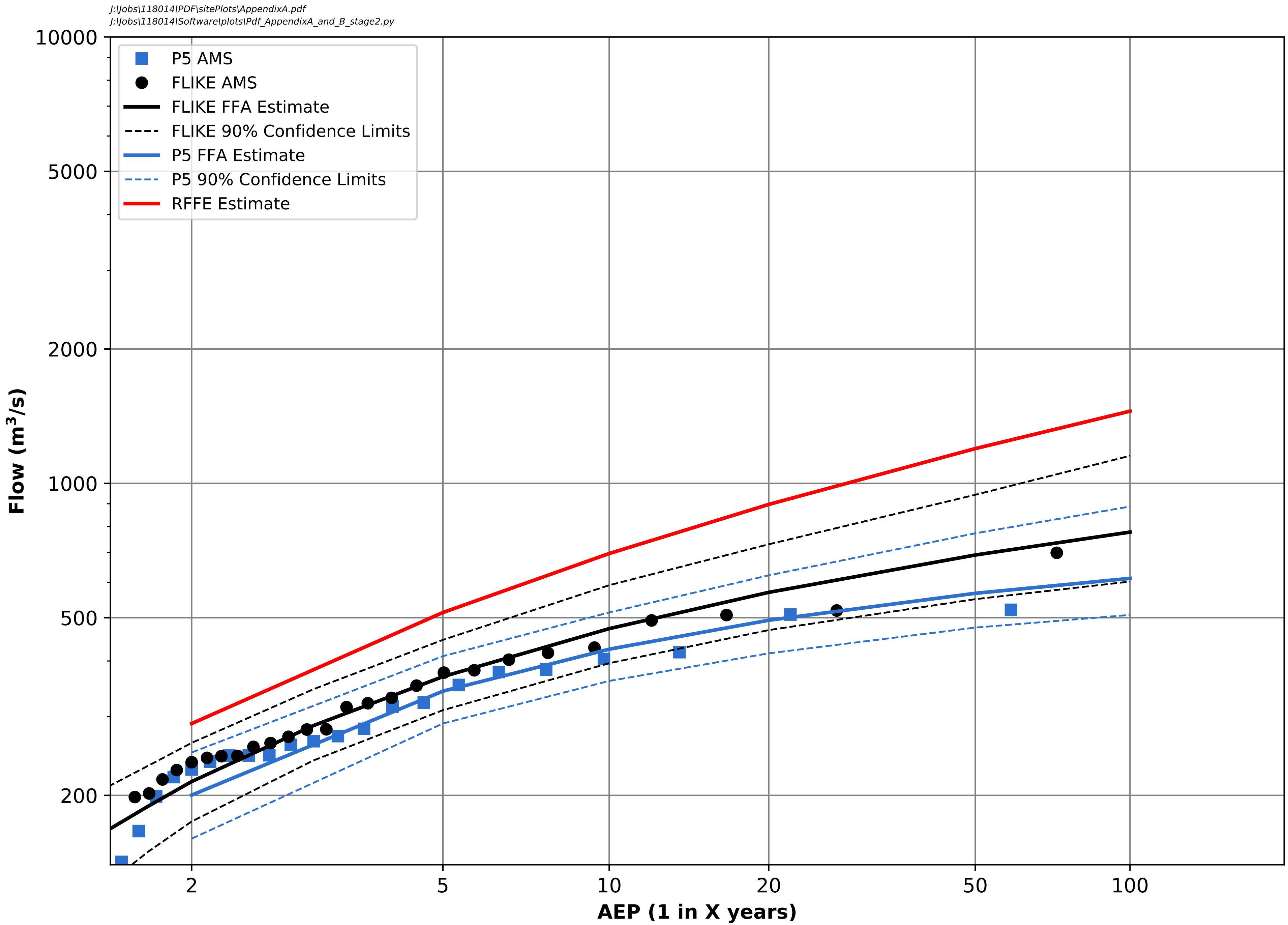


BINNA BURRA - 203012 [I25]
FFA VARIANTS
APPENDIX A133



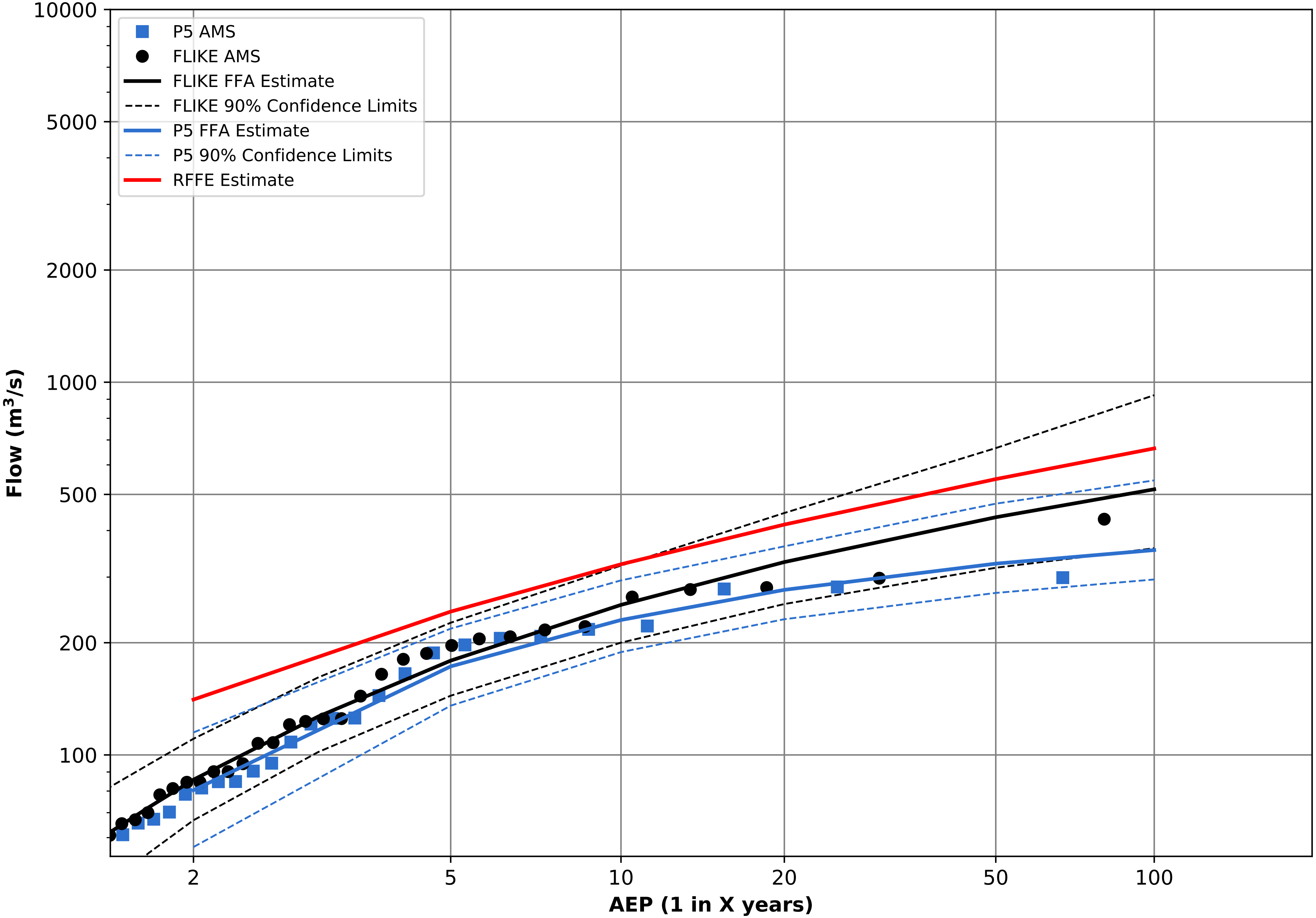
ROCK VALLEY - 203010 [I26]
FFA VARIANTS



REPENTANCE - 203002 [I27]

FFA VARIANTS

APPENDIX A135



DURRUMBUL (SHERRYS CROSSING) - 202001 [I28]
FFA VARIANTS

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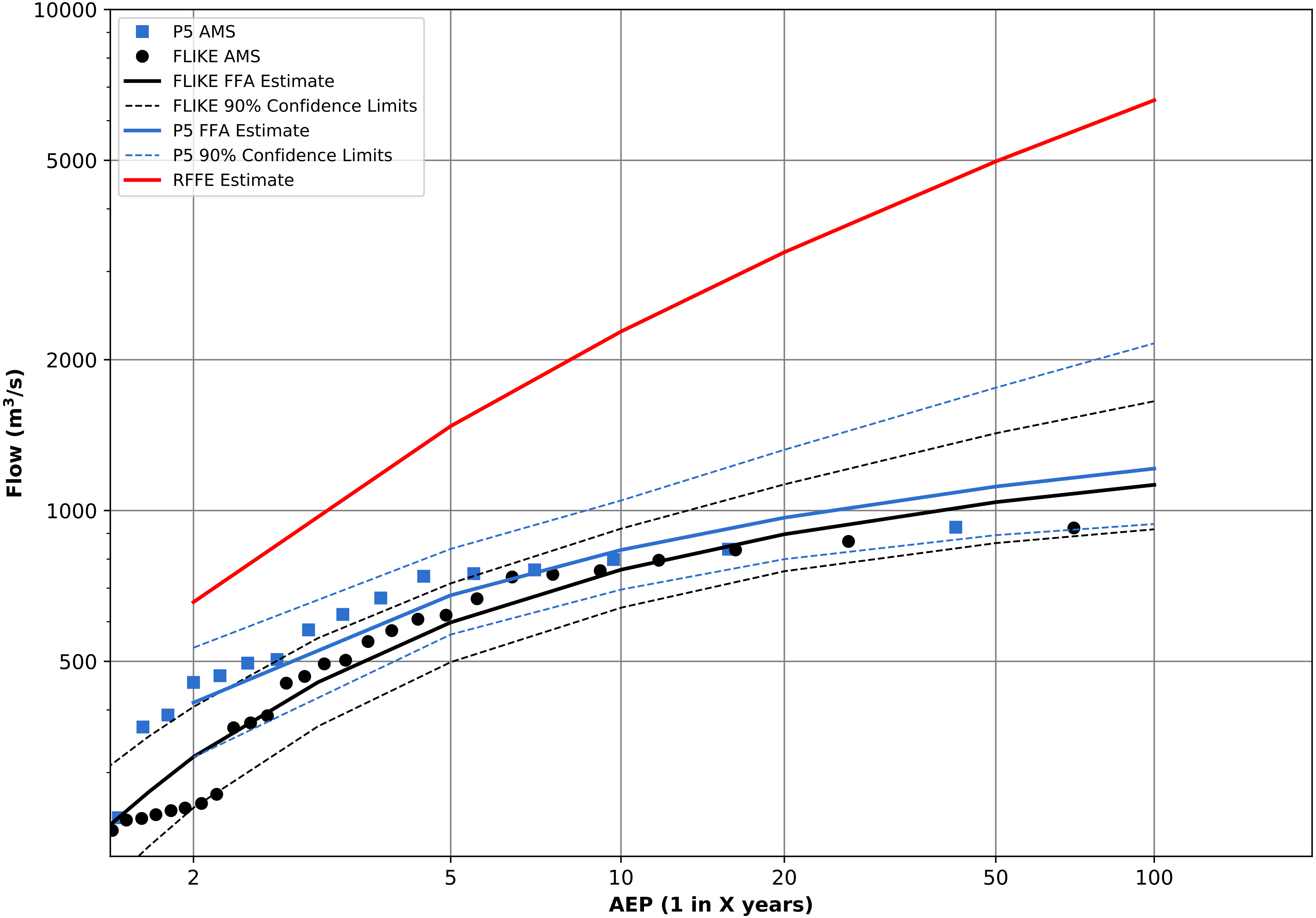
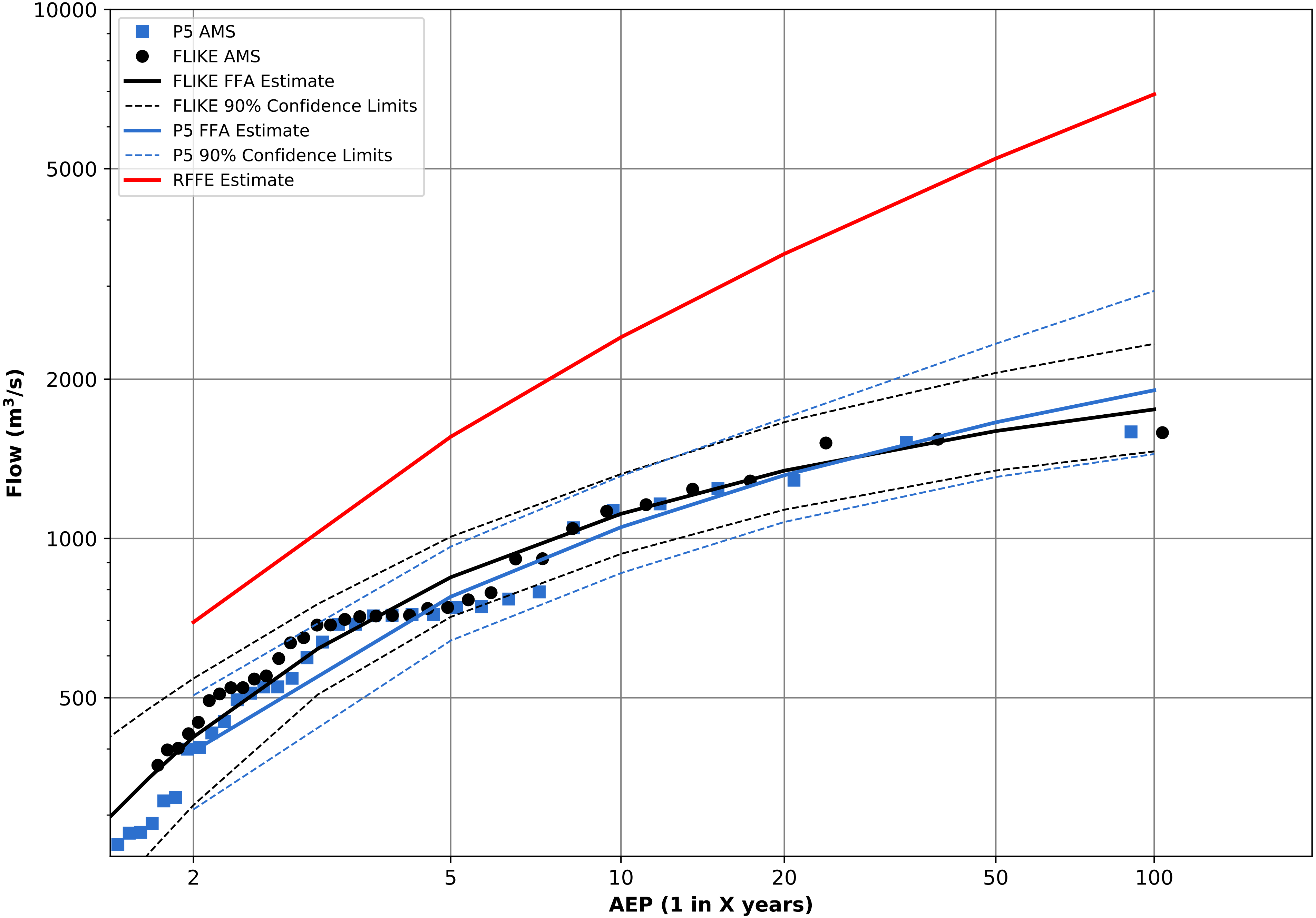


BOAT HARBOUR NO.20.55 CM - 201005 [I29]

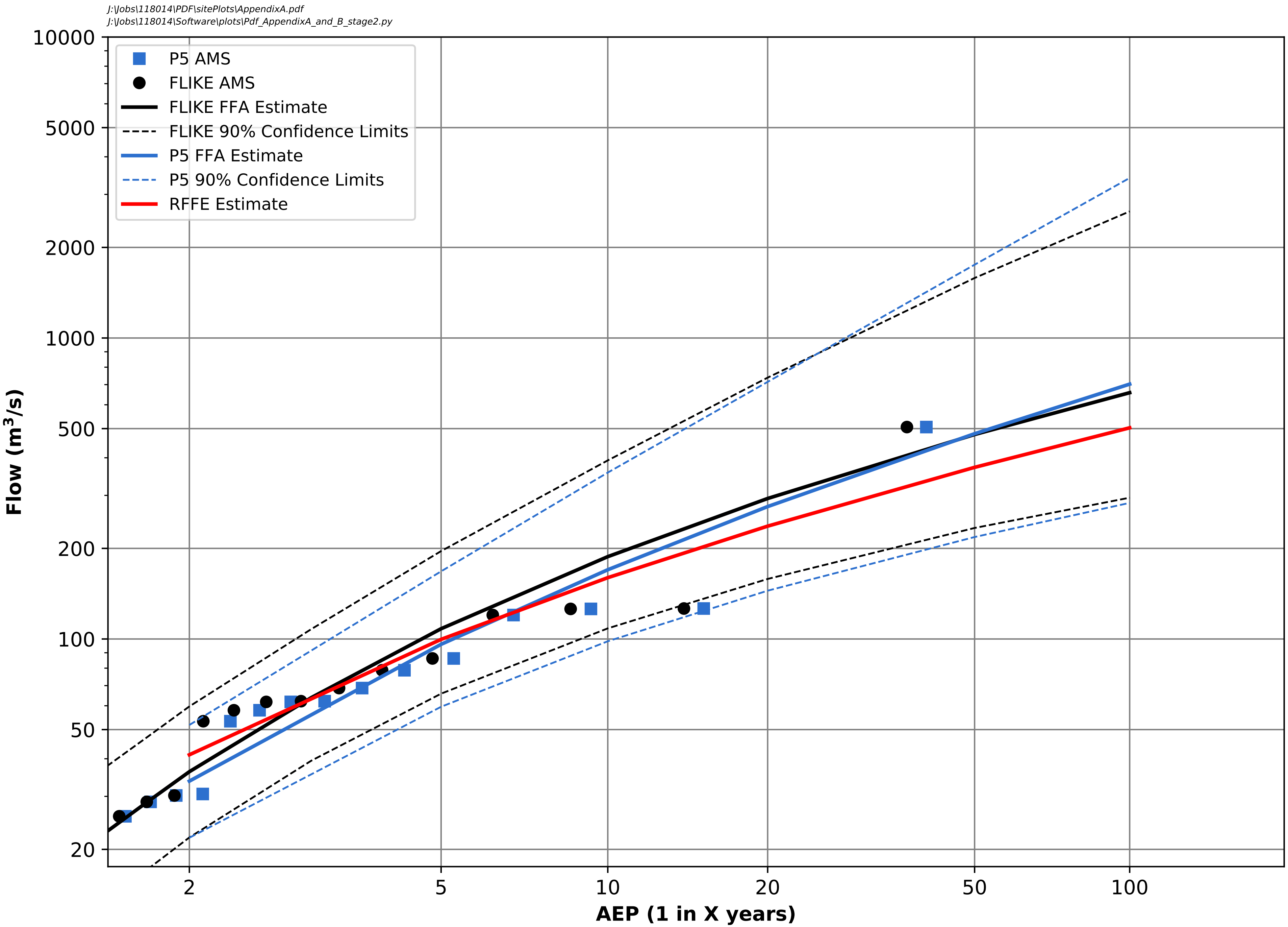
FFA VARIANTS

APPENDIX A137



EUNGELLA - 201001 [I30]

FFA VARIANTS



DAMSITE - 419044 [J1]

FFA VARIANTS

APPENDIX A139

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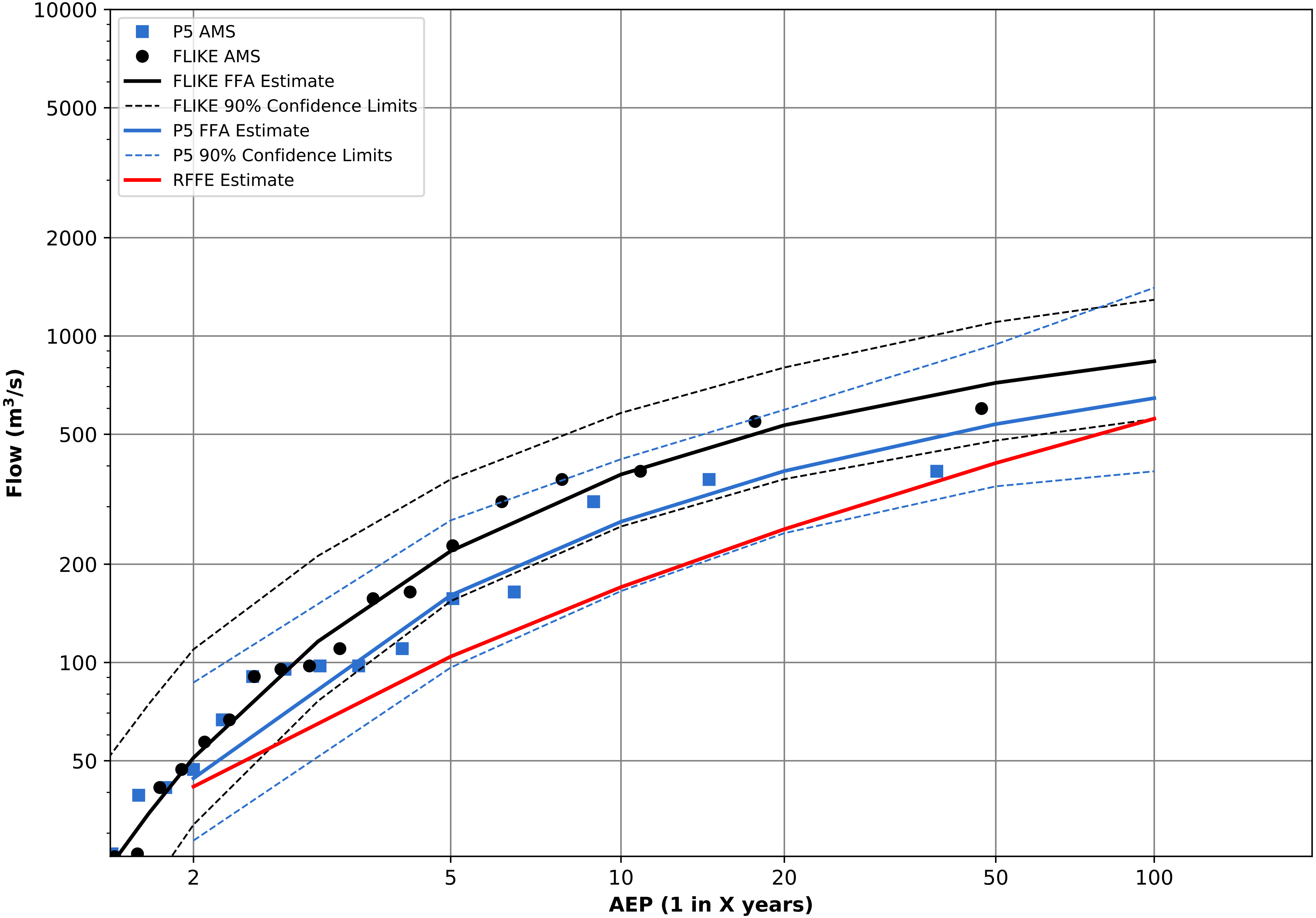

WOODSREEF - 419047 [J2]
FFA VARIANTS
APPENDIX A140

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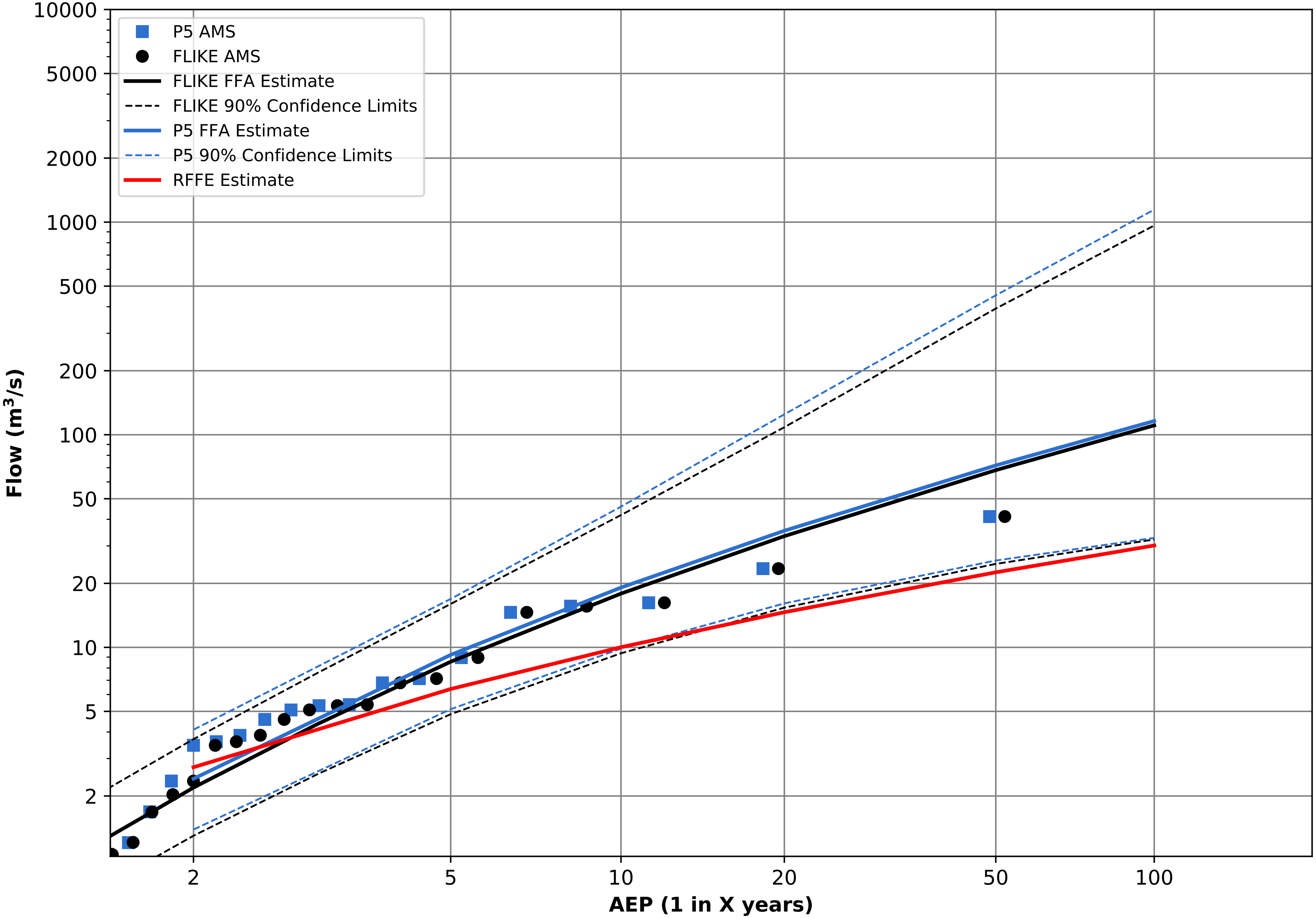
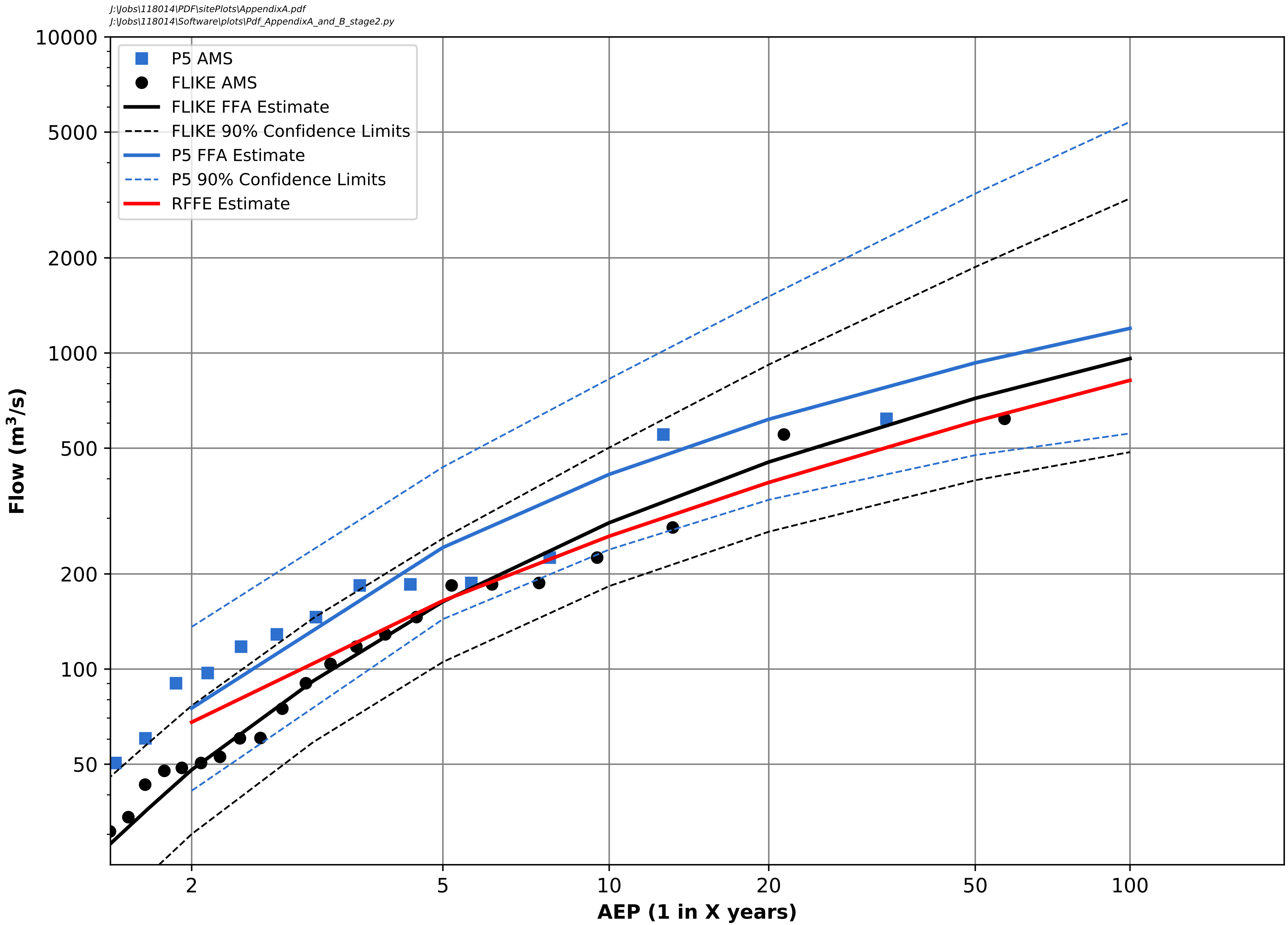


BLACK MOUNTAIN - 418034 [J3]
FFA VARIANTS
APPENDIX A141



SHANNON VALE - 204031 [J4]

FFA VARIANTS

APPENDIX A142

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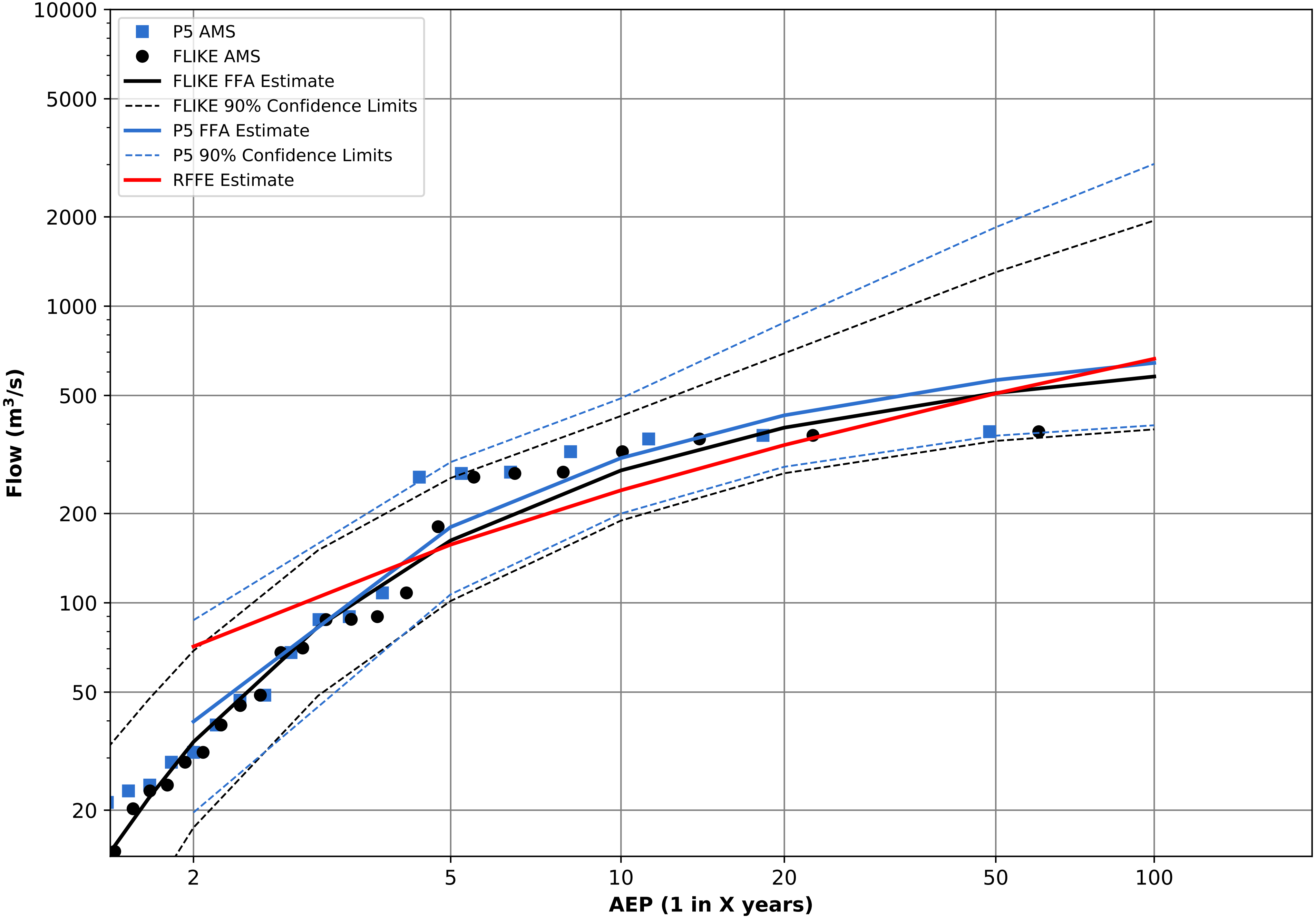
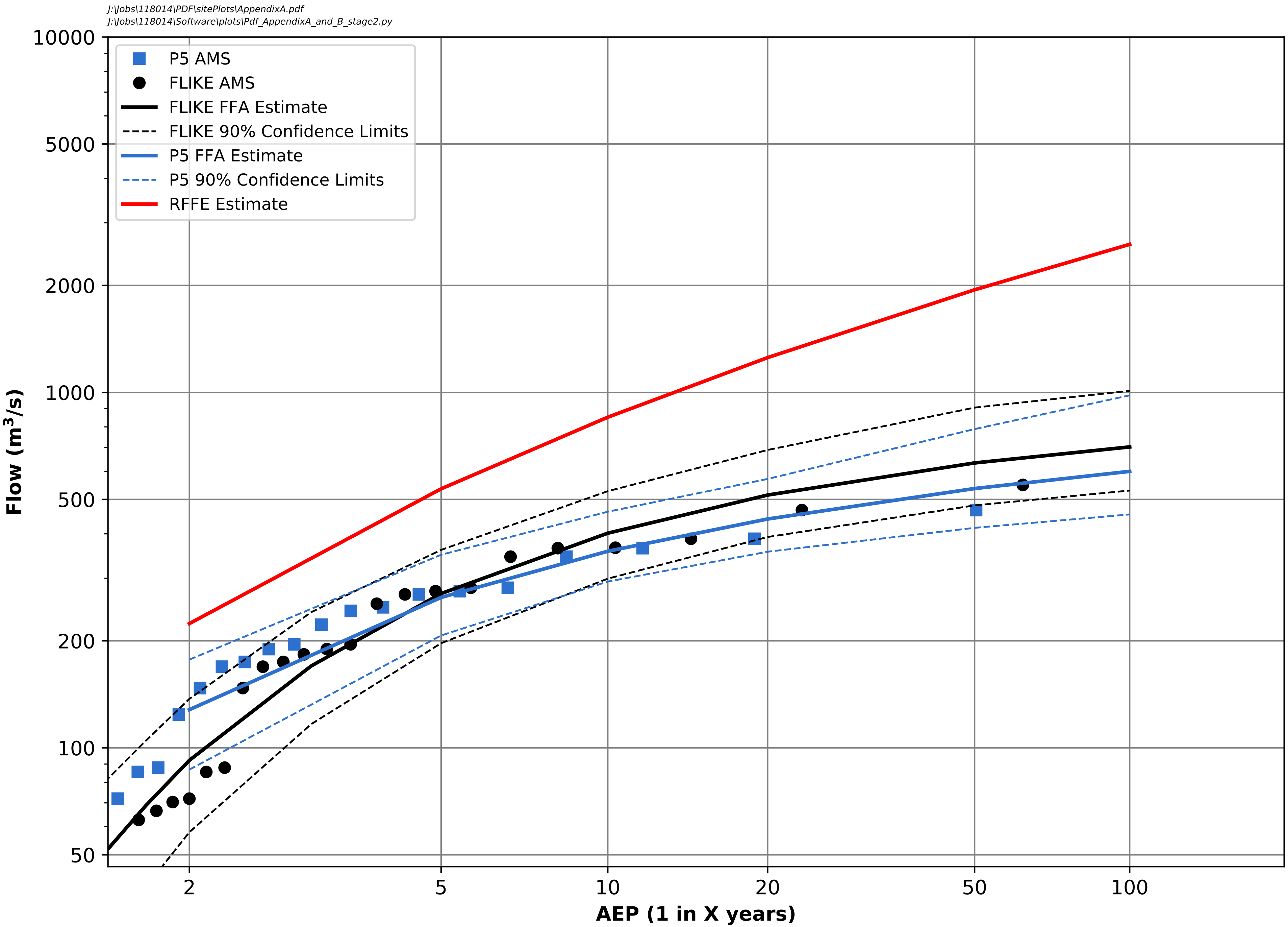
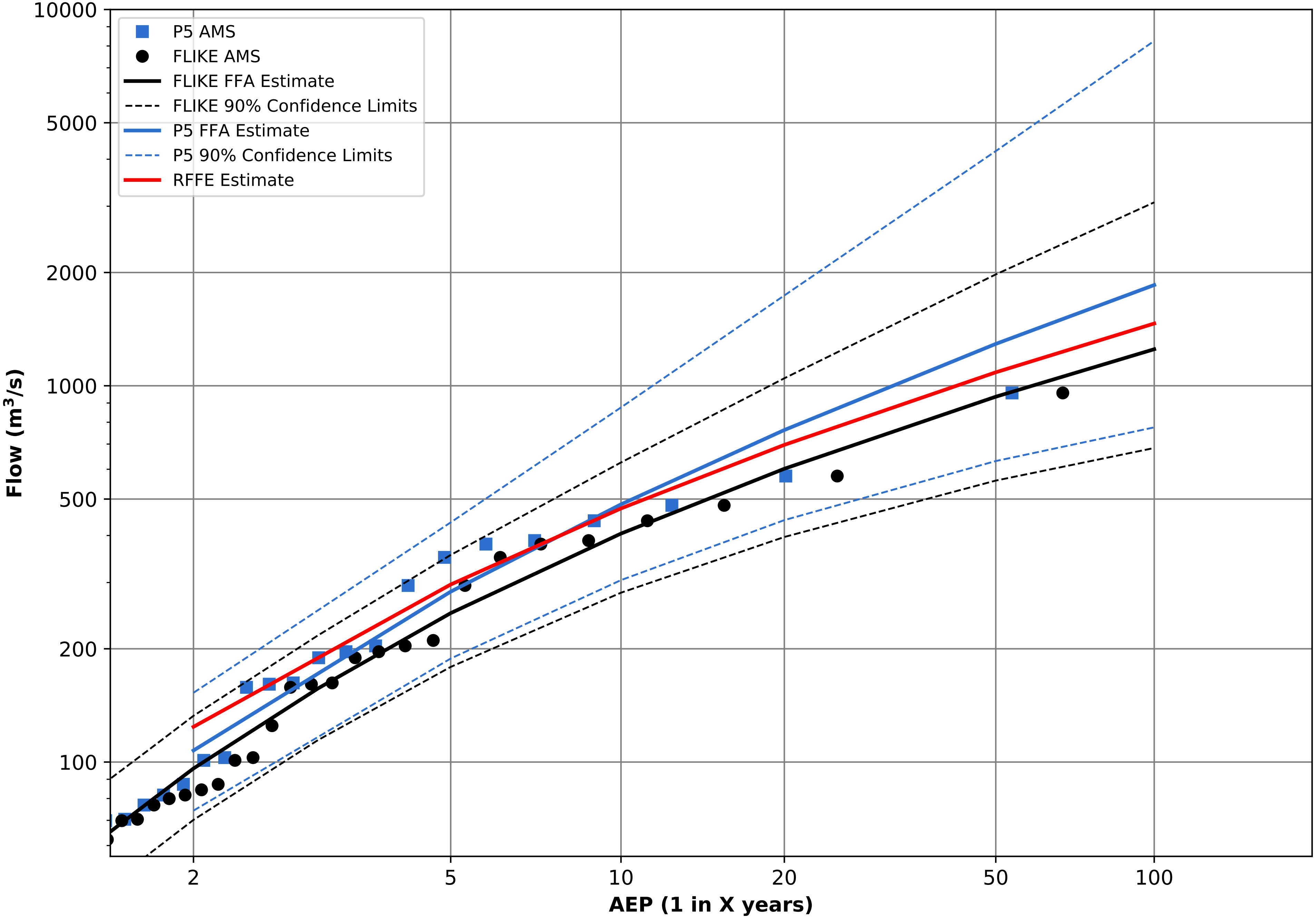


OLD WARRAH - 419076 [J5]
FFA VARIANTS
APPENDIX A143



TIMBUMBURI - 419035 [J6]
FFA VARIANTS

APPENDIX A144



FFA VARIANTS
WOOLBROOK - 419010 [J7]

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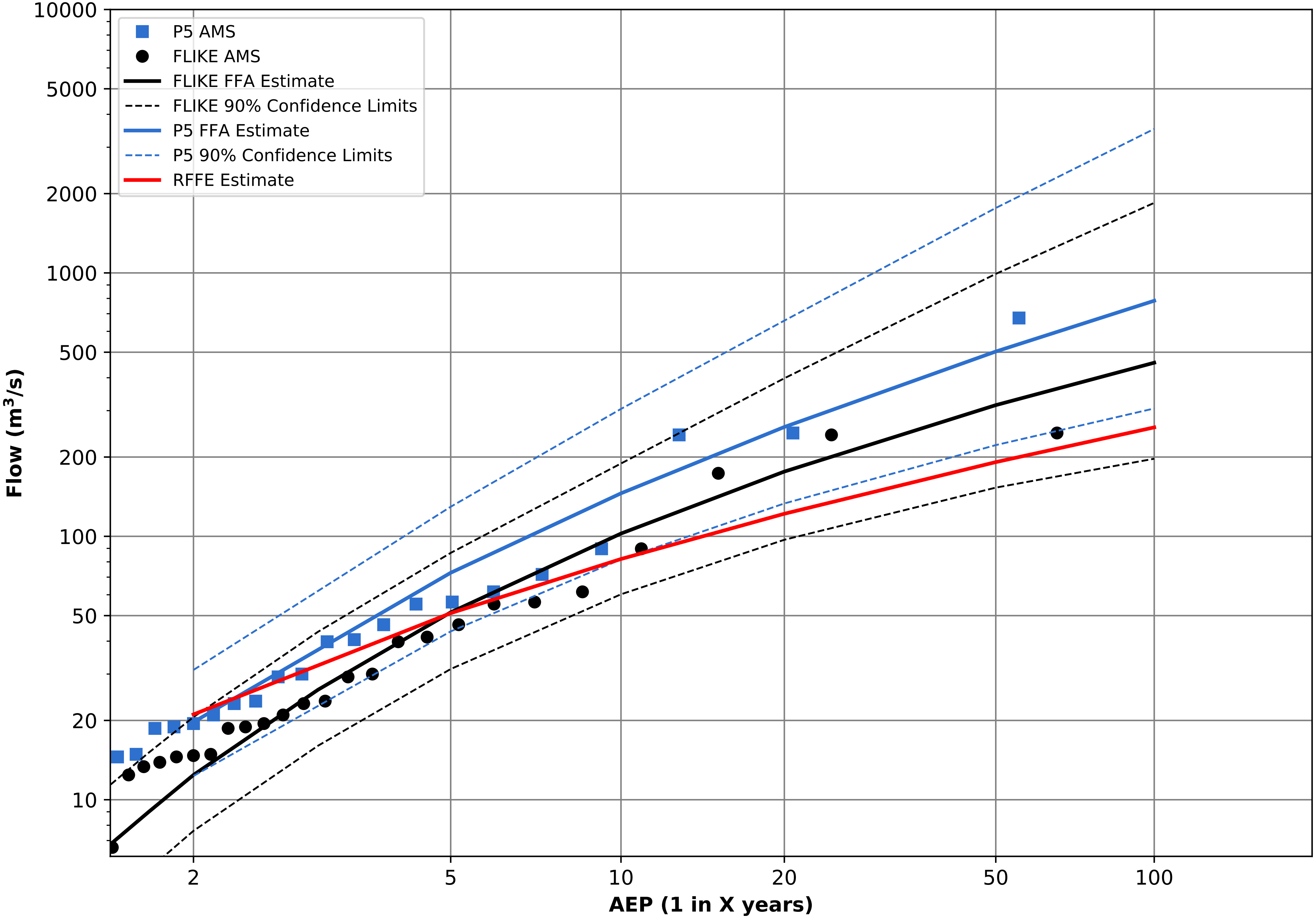

UKOLAN - 419029 [J8]
FFA VARIANTS
APPENDIX A146

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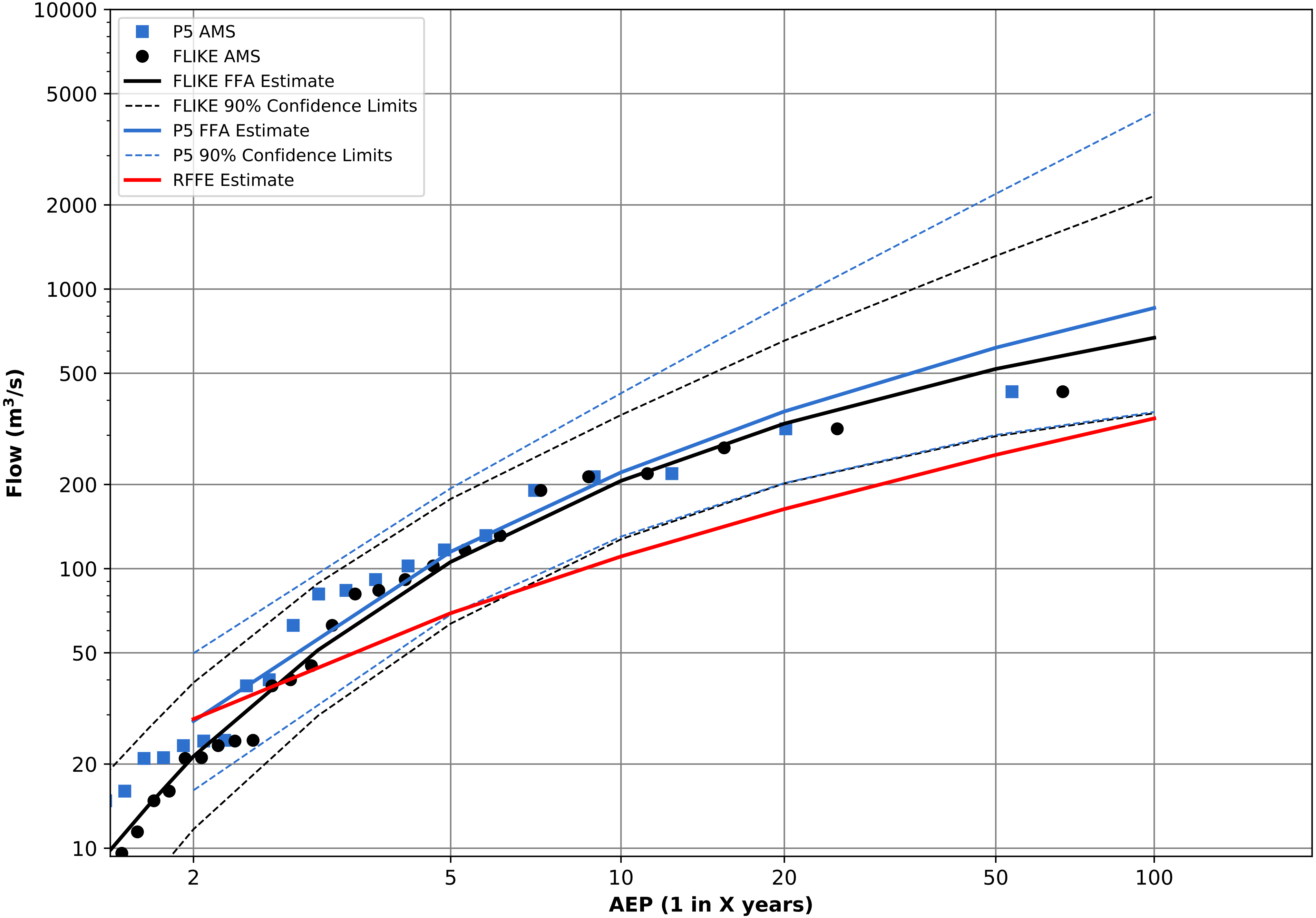

BINGARA - 418025 [J9]

FFA VARIANTS

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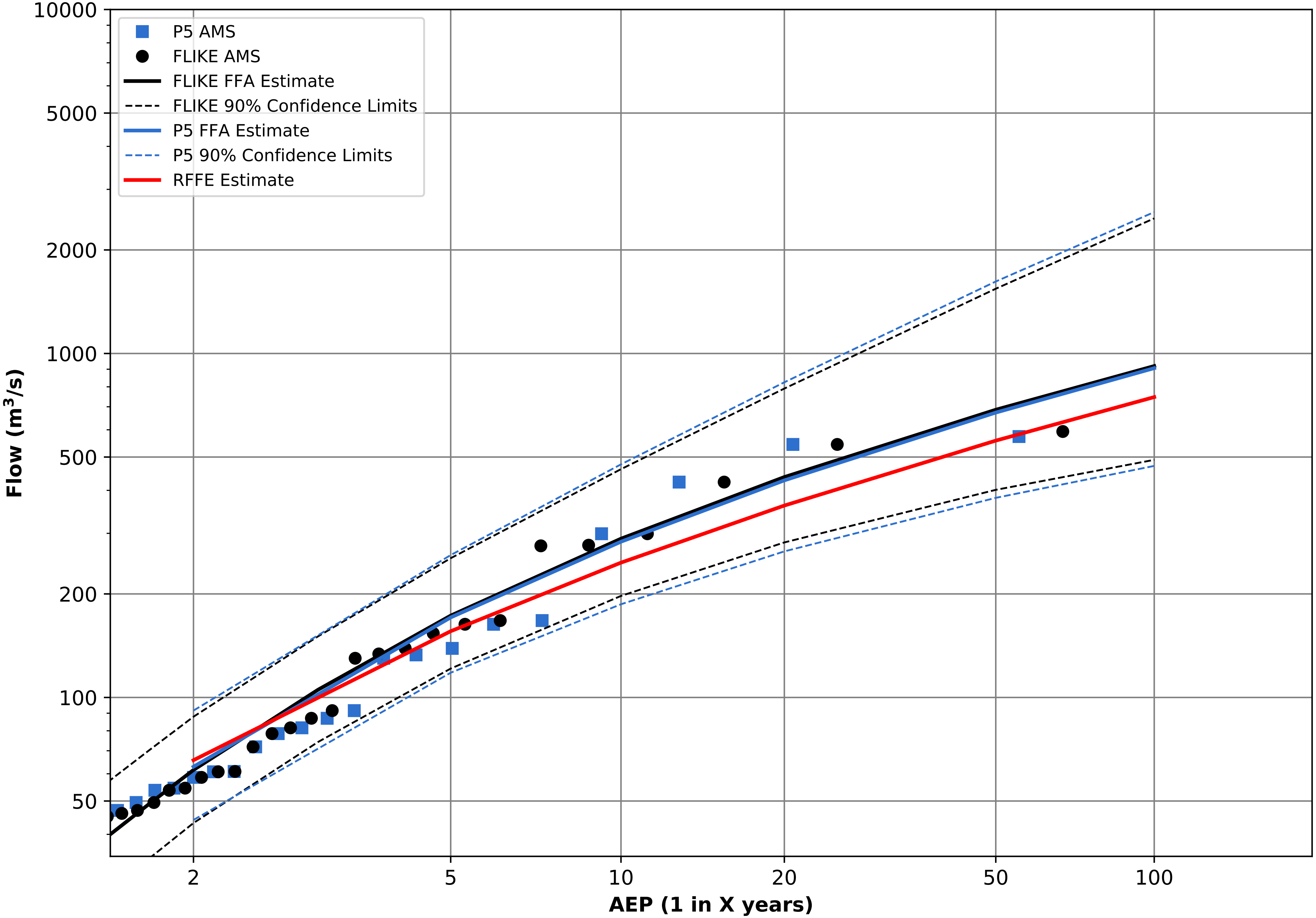
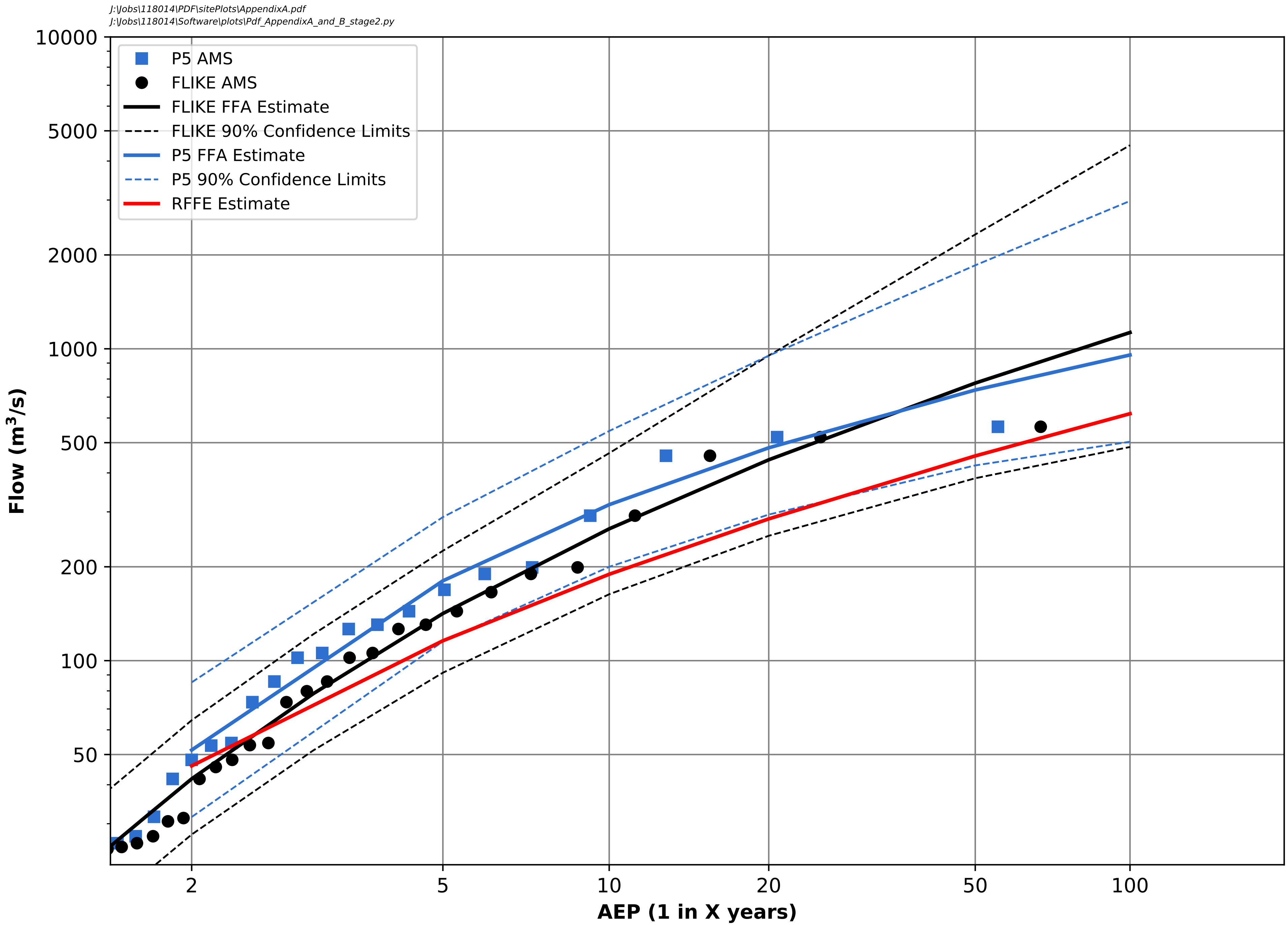


BOLIVIA - 416023 [J10]

FFA VARIANTS

APPENDIX A148



APPENDIX A149

FFA VARIANTS

COOLATAI - 416020 [J11]

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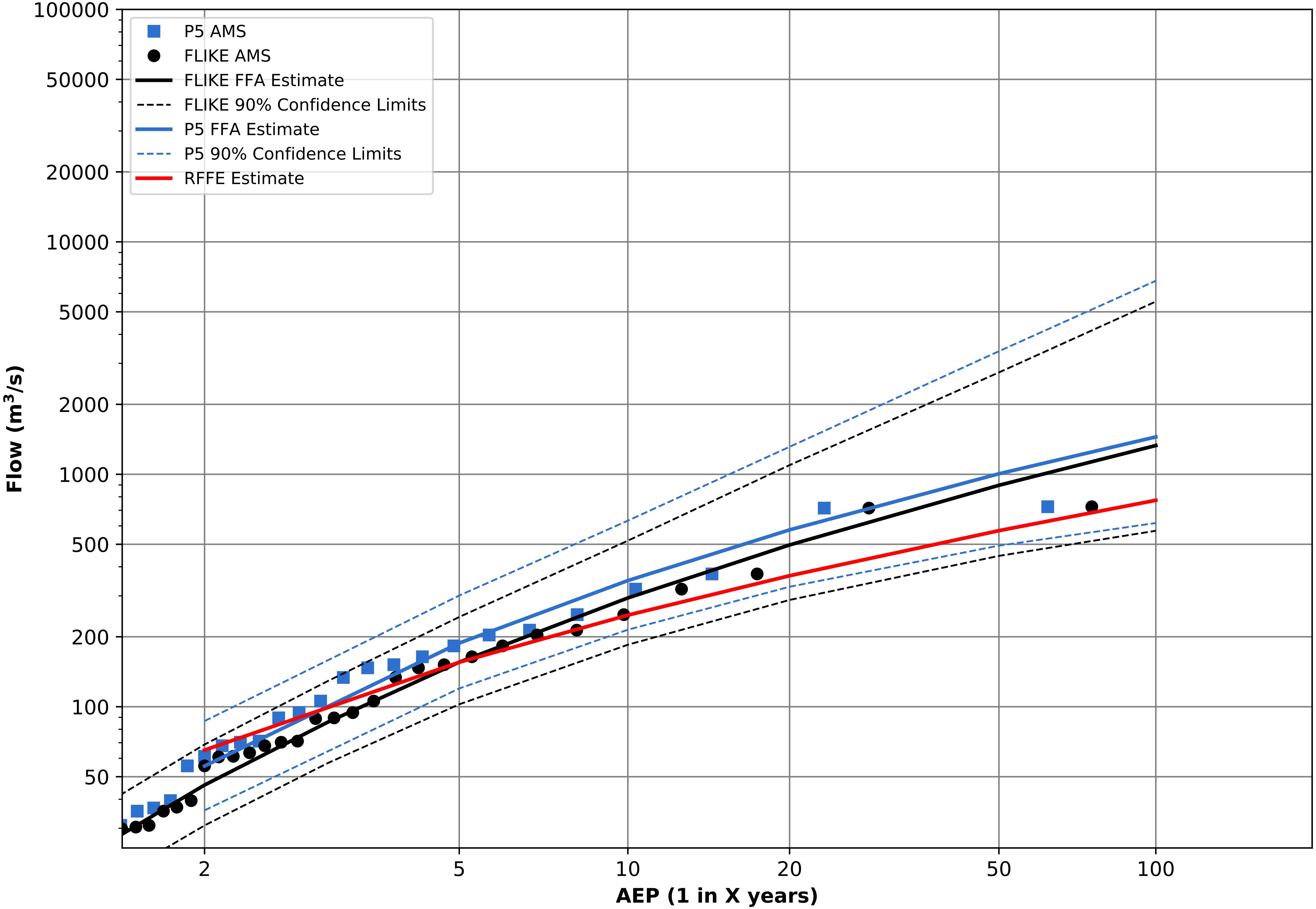

LIMBRI - 419054 [J12]
FFA VARIANTS
APPENDIX A150

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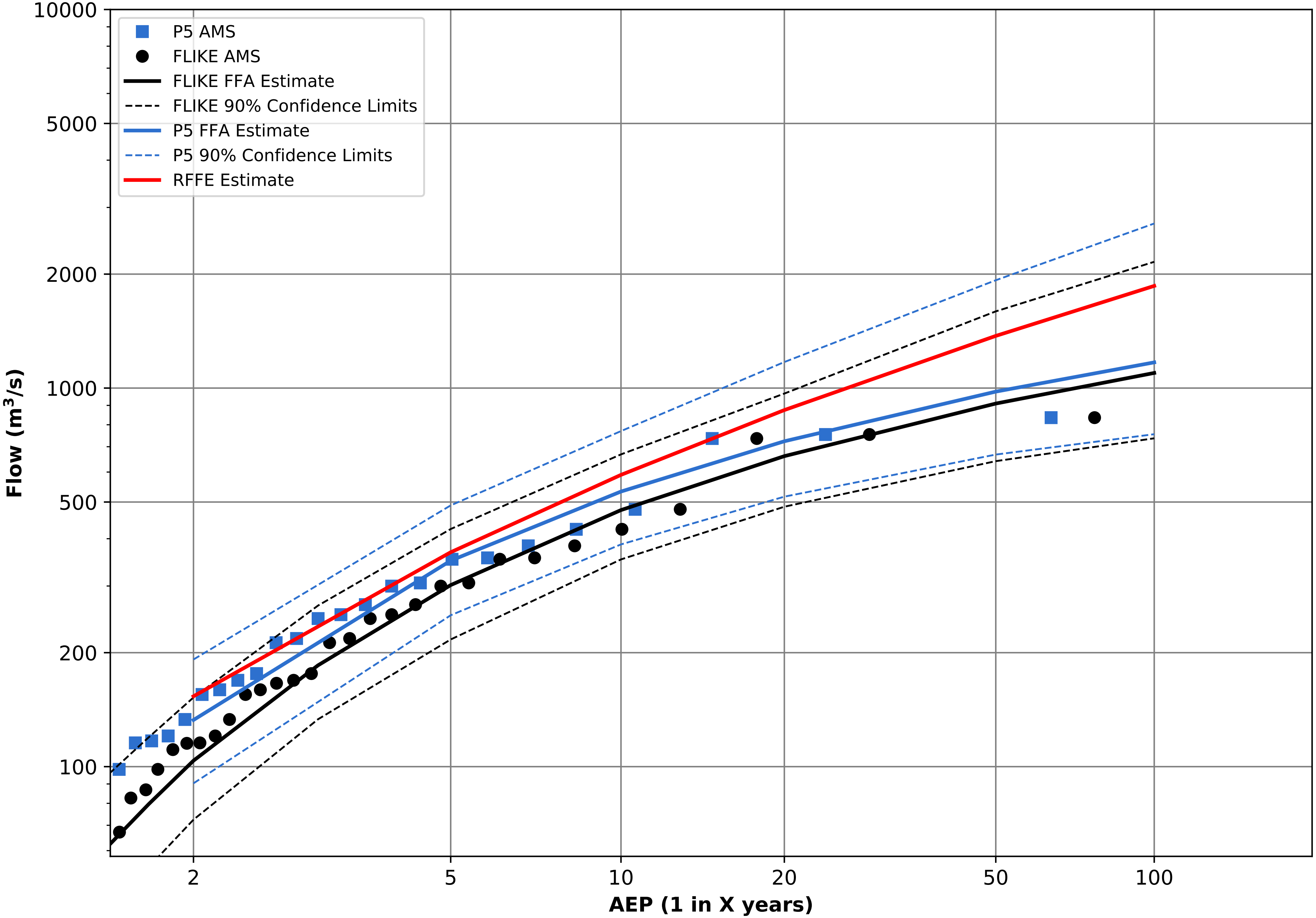

MULLA CROSSING - 419016 [J13]
FFA VARIANTS
APPENDIX A151

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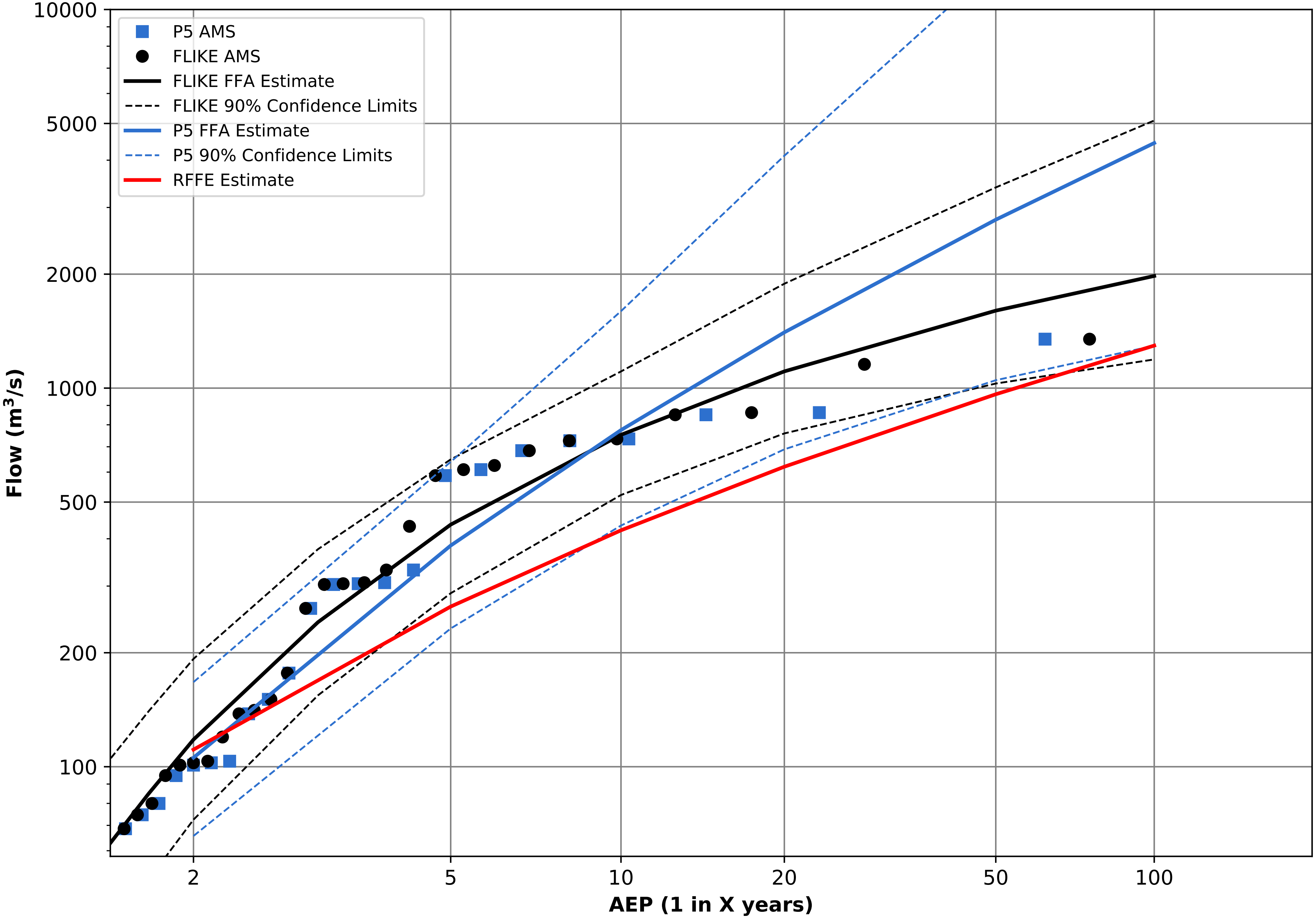

APPENDIX A152

FFA VARIANTS

BLACK SPRINGS - 419053 [J14]

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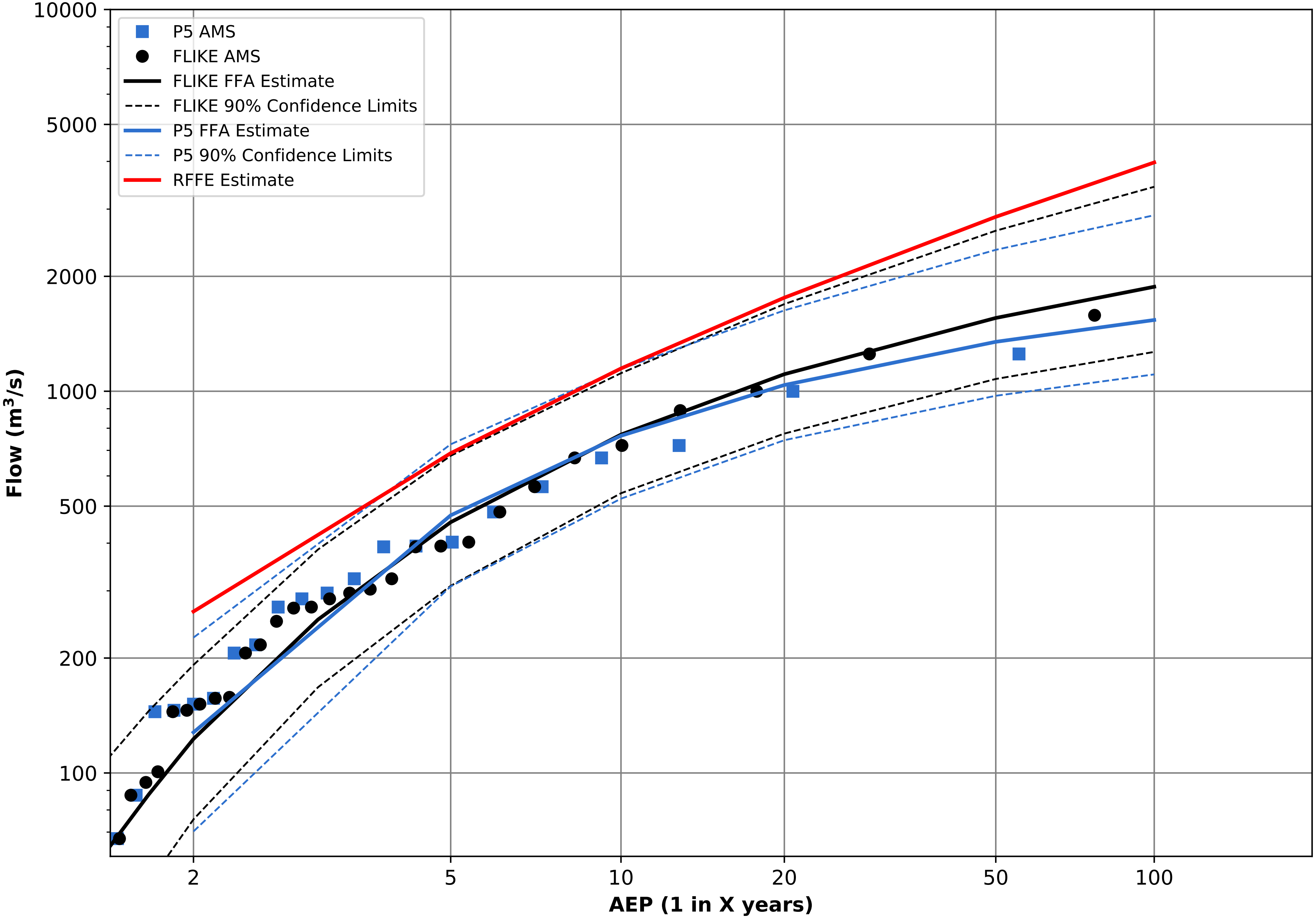

MOLROY - 418017 [J15]
FFA VARIANTS
APPENDIX A153

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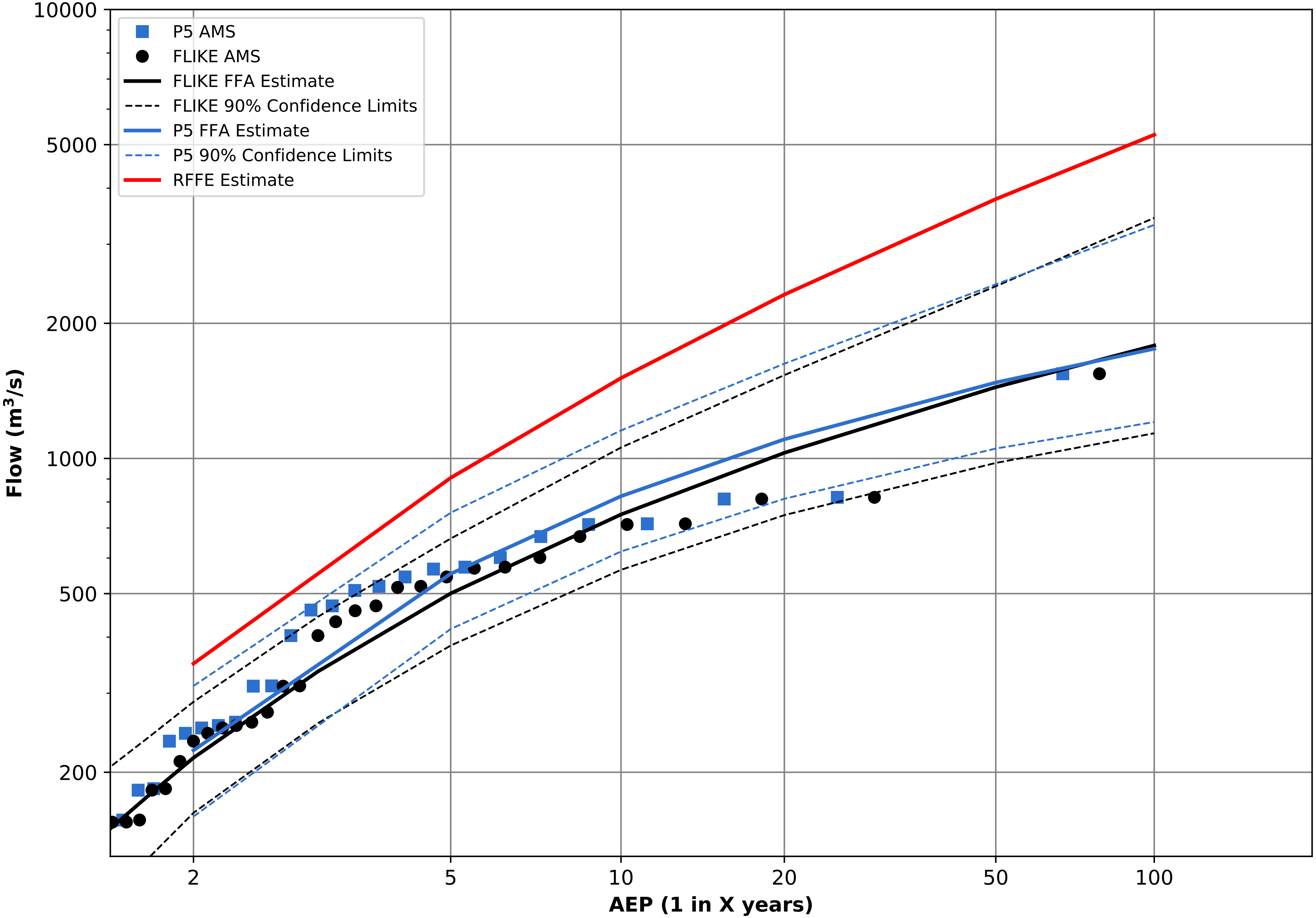

INVERELL (MIDDLE CK) - 416016 [J16]
FFA VARIANTS

APPENDIX A154

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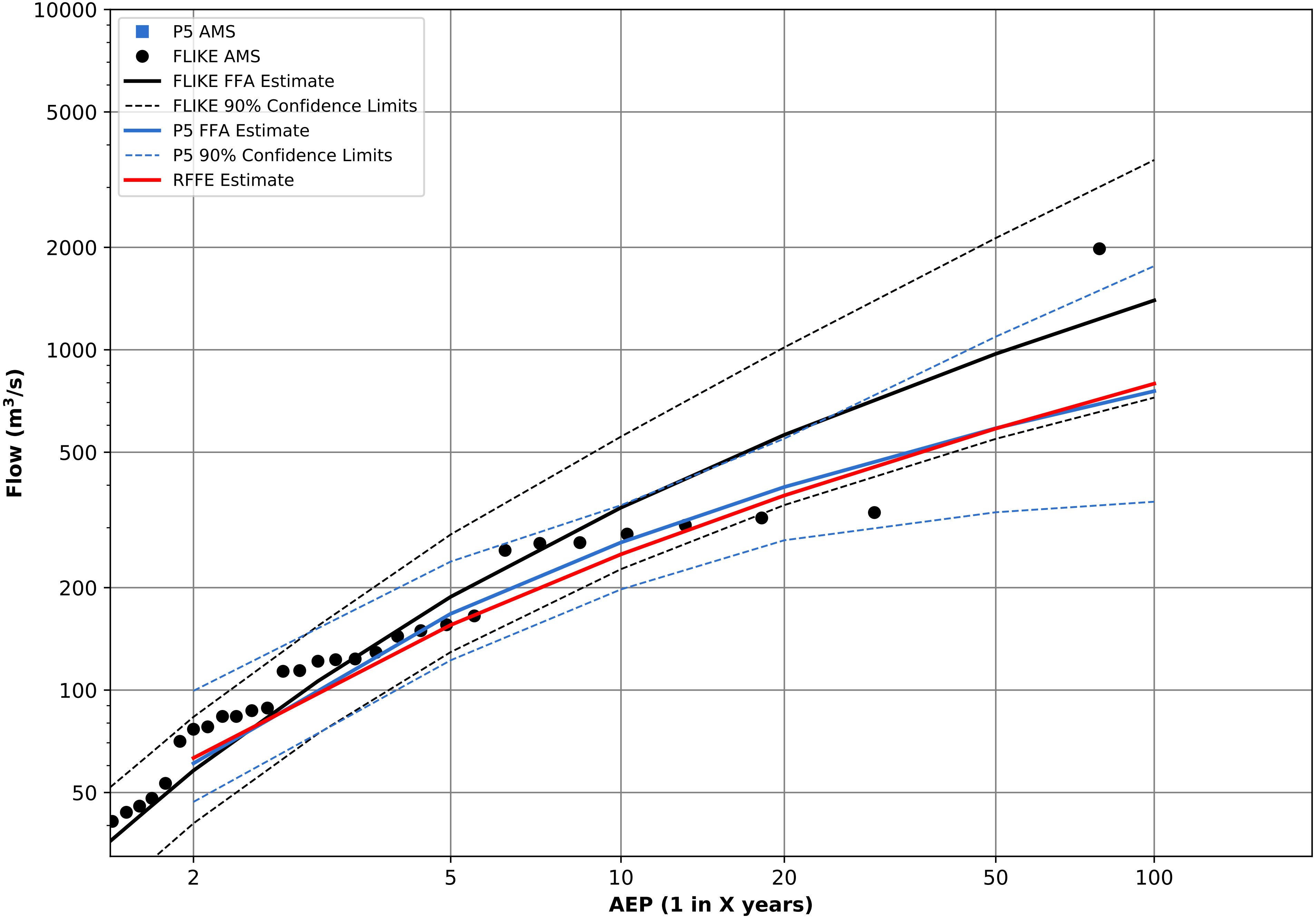

APPENDIX A155

FFA VARIANTS

CLIFTON - 416003 [J17]

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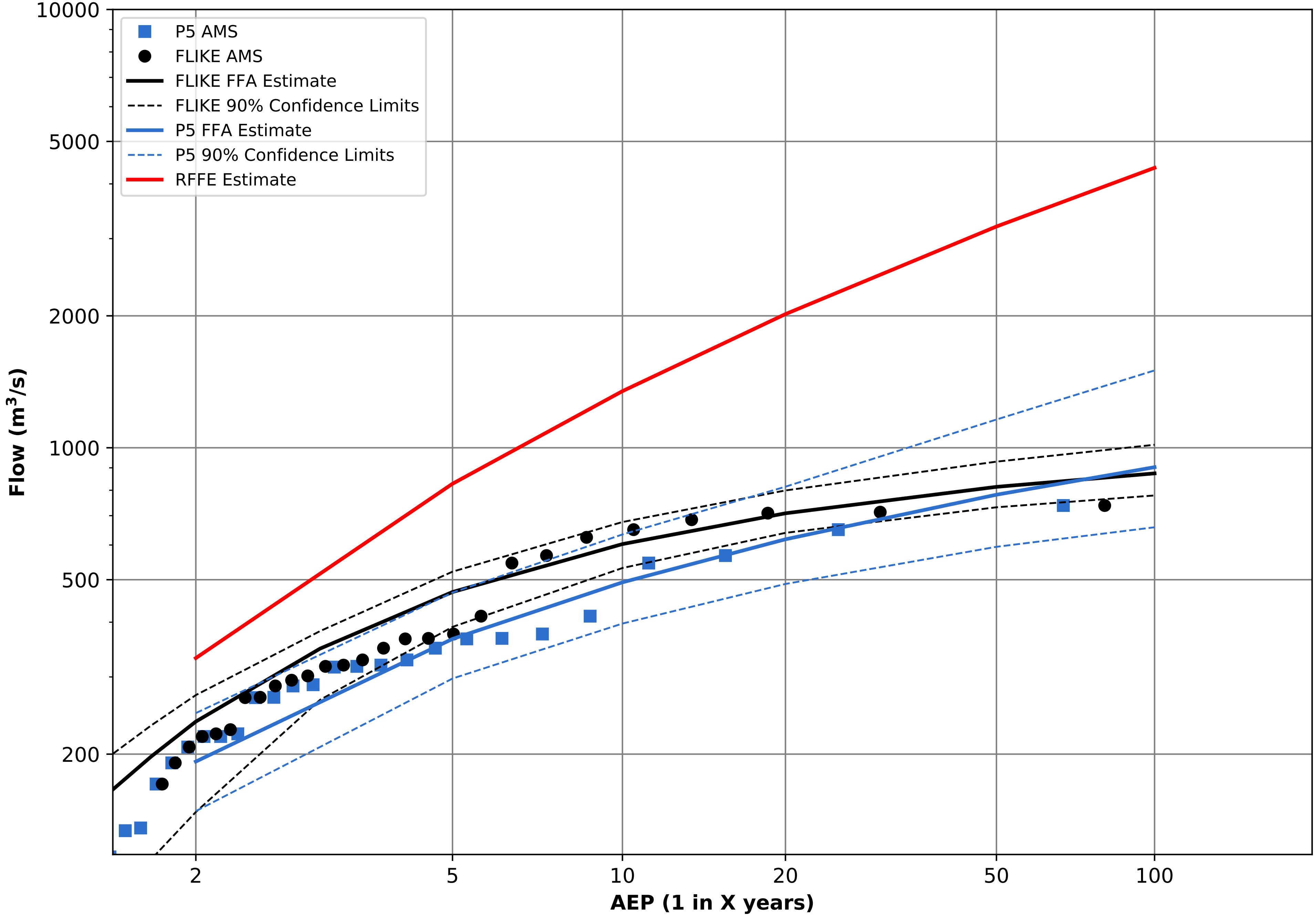

HAYSTACK - 416008 [J18]

FFA VARIANTS

APPENDIX A156

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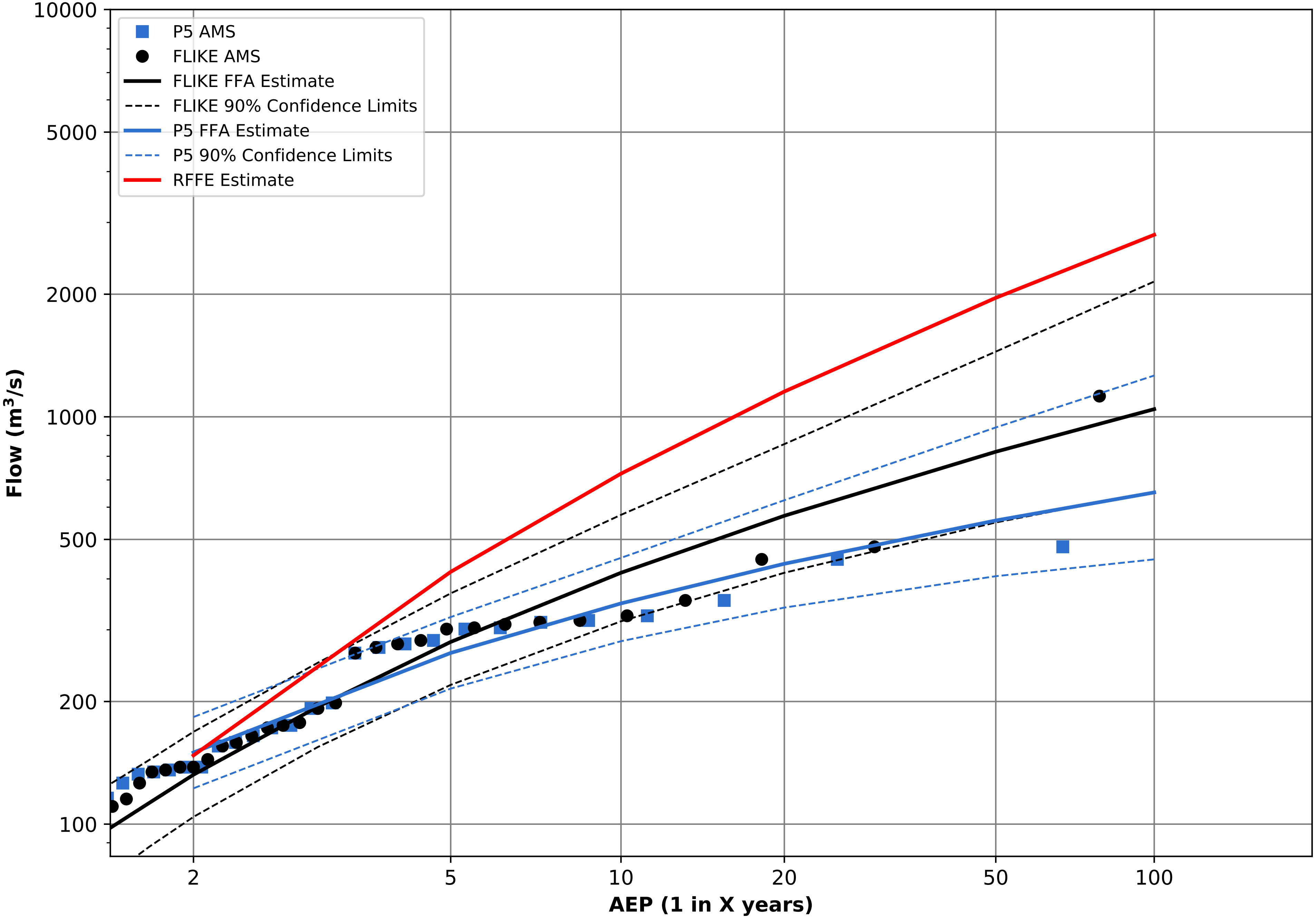

HORTON DAM SITE - 418027 [J19]

FFA VARIANTS

APPENDIX A157

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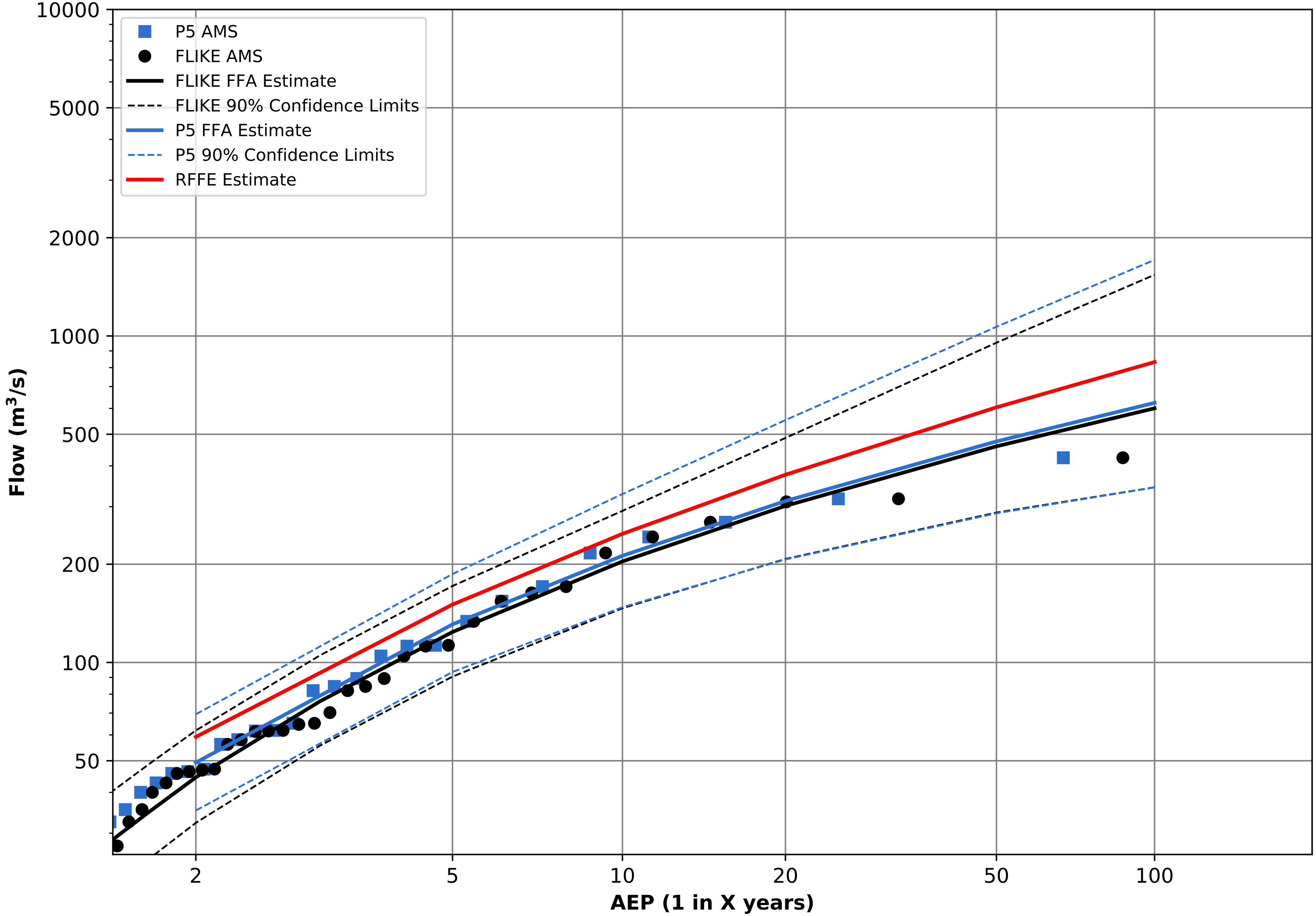

KIMBERLEY - 418005 [J20]

FFA VARIANTS

APPENDIX A158

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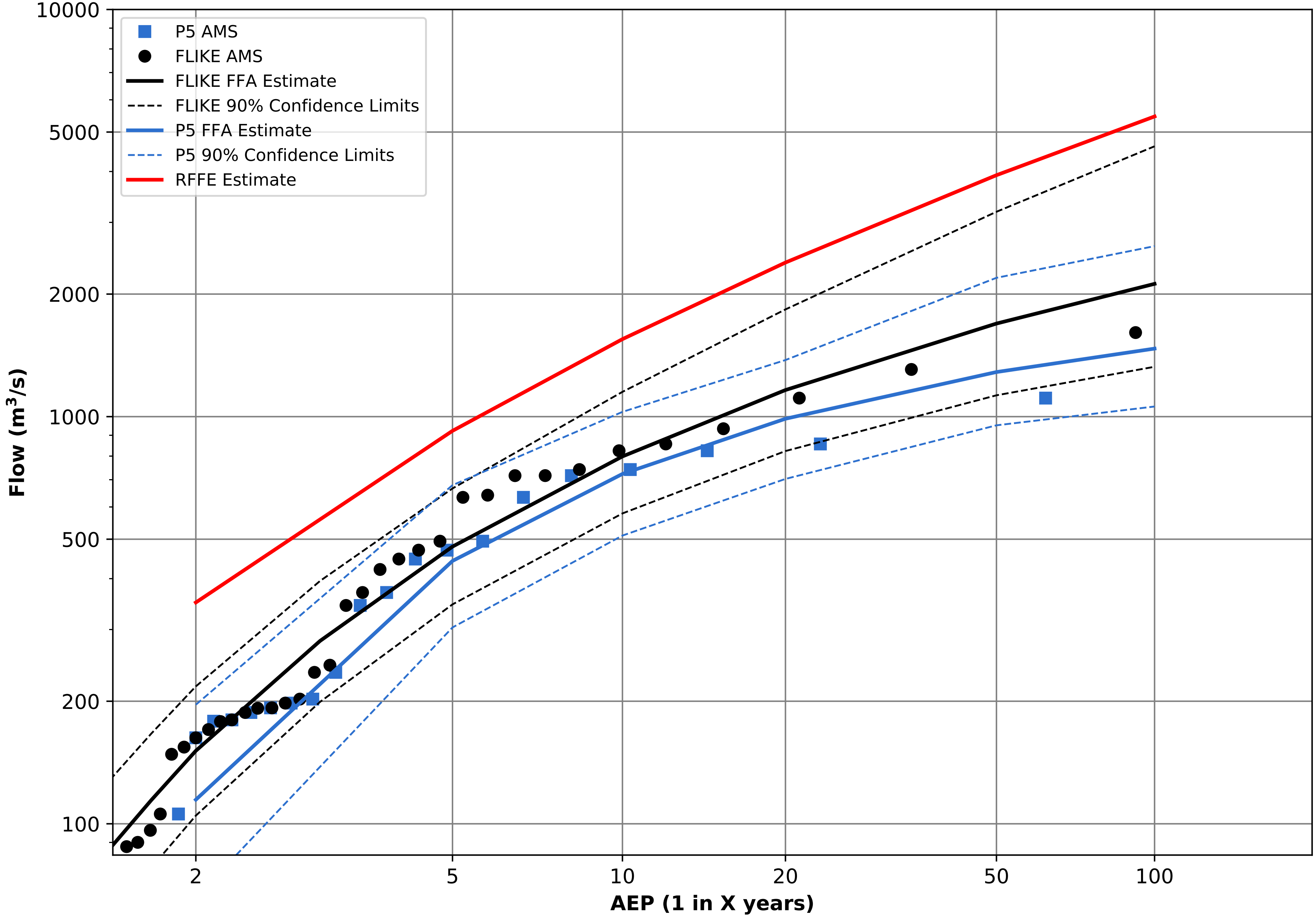

YARROWYCK - 418014 [J21]
FFA VARIANTS
APPENDIX A159

Appendix B

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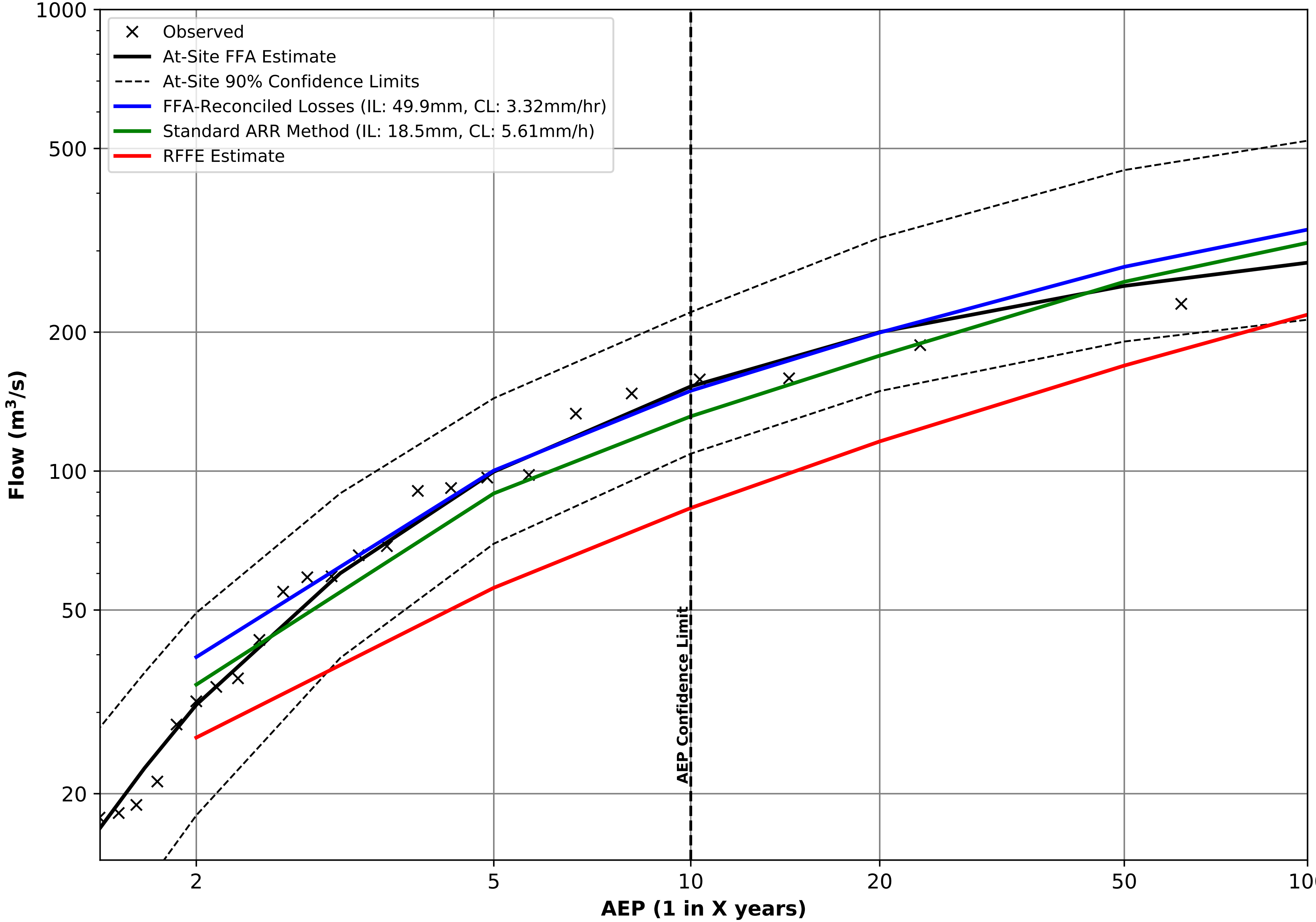

METHOD COMPARISON
IMLAY RD BR - 221010 [A1]

APPENDIX B1

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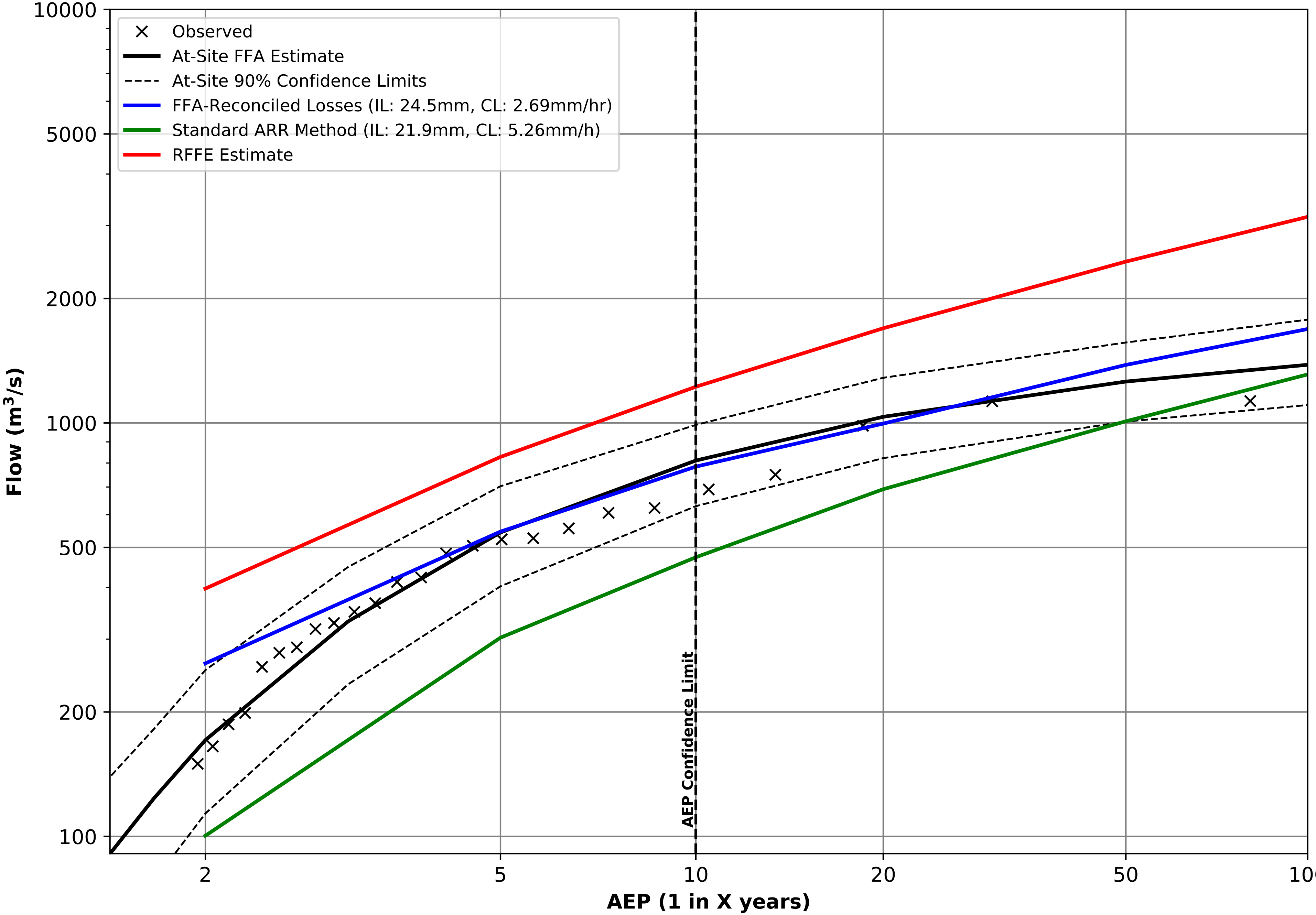
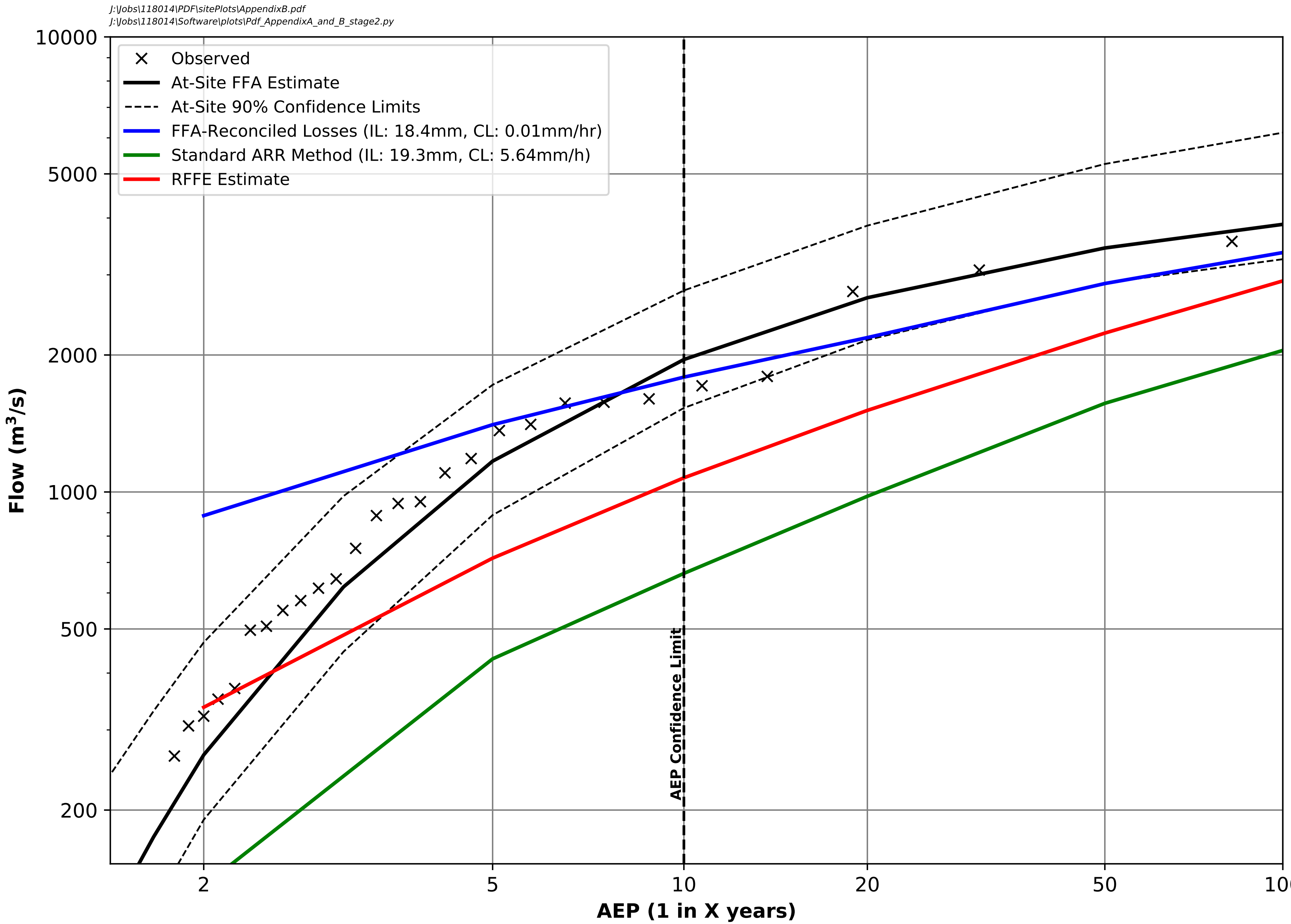


METHOD COMPARISON
PRINCES HWY - 221002 [A2]

APPENDIX B2



METHOD COMPARISON
TOWAMBA - 220004 [A3]

APPENDIX B3

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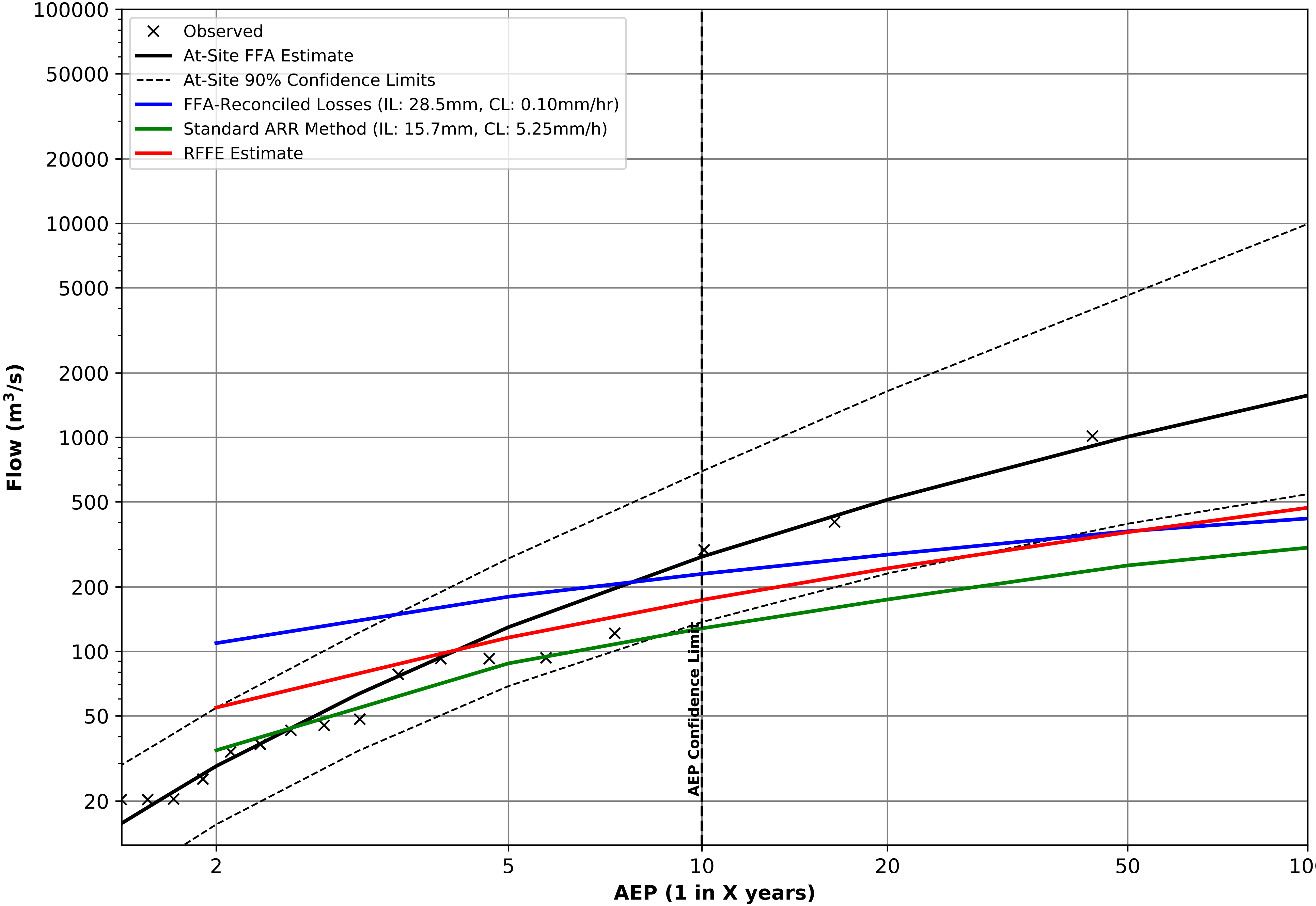

ROCKY HALL (WHITBYS) - 220002 [A4]
METHOD COMPARISON

APPENDIX B4

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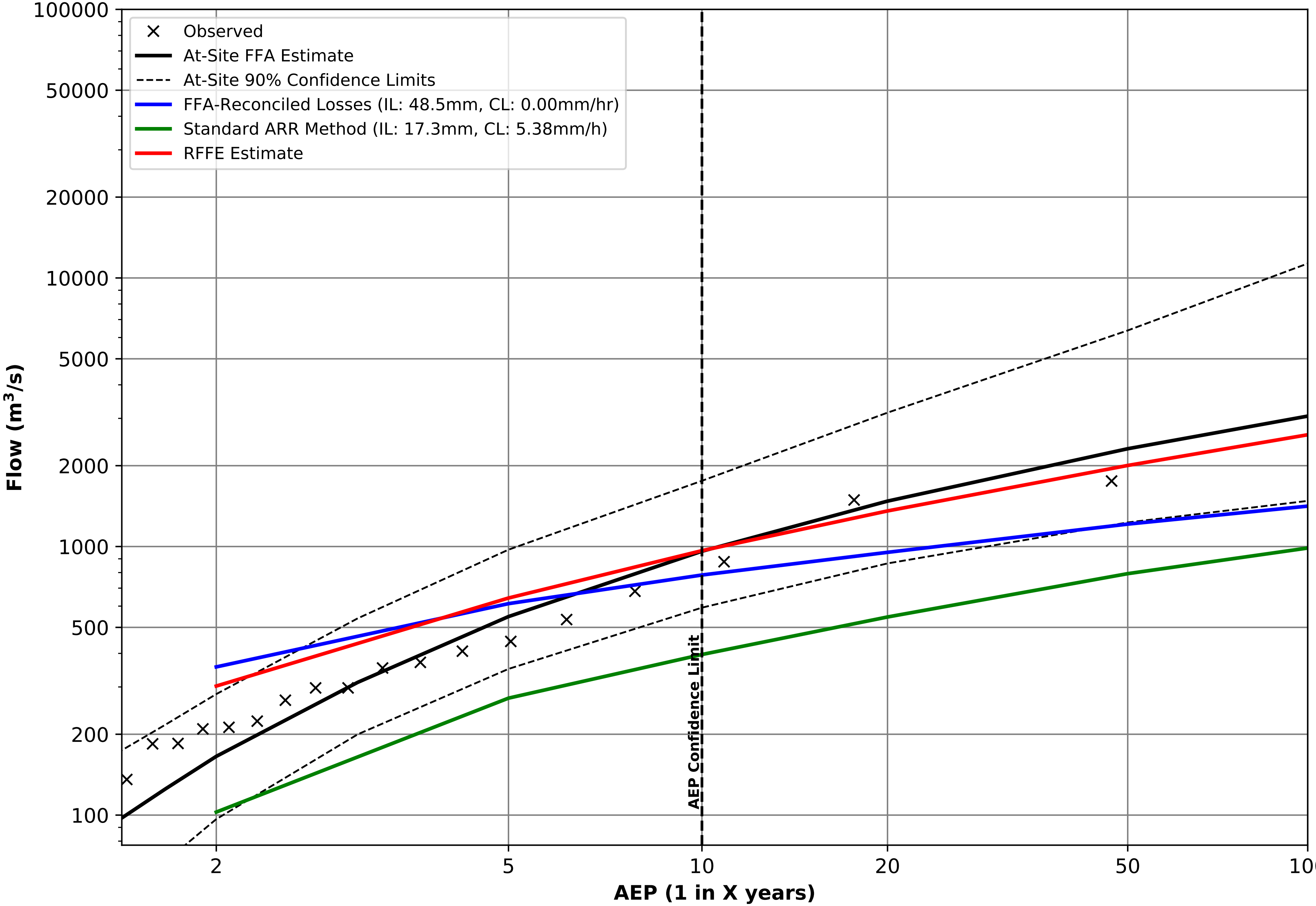
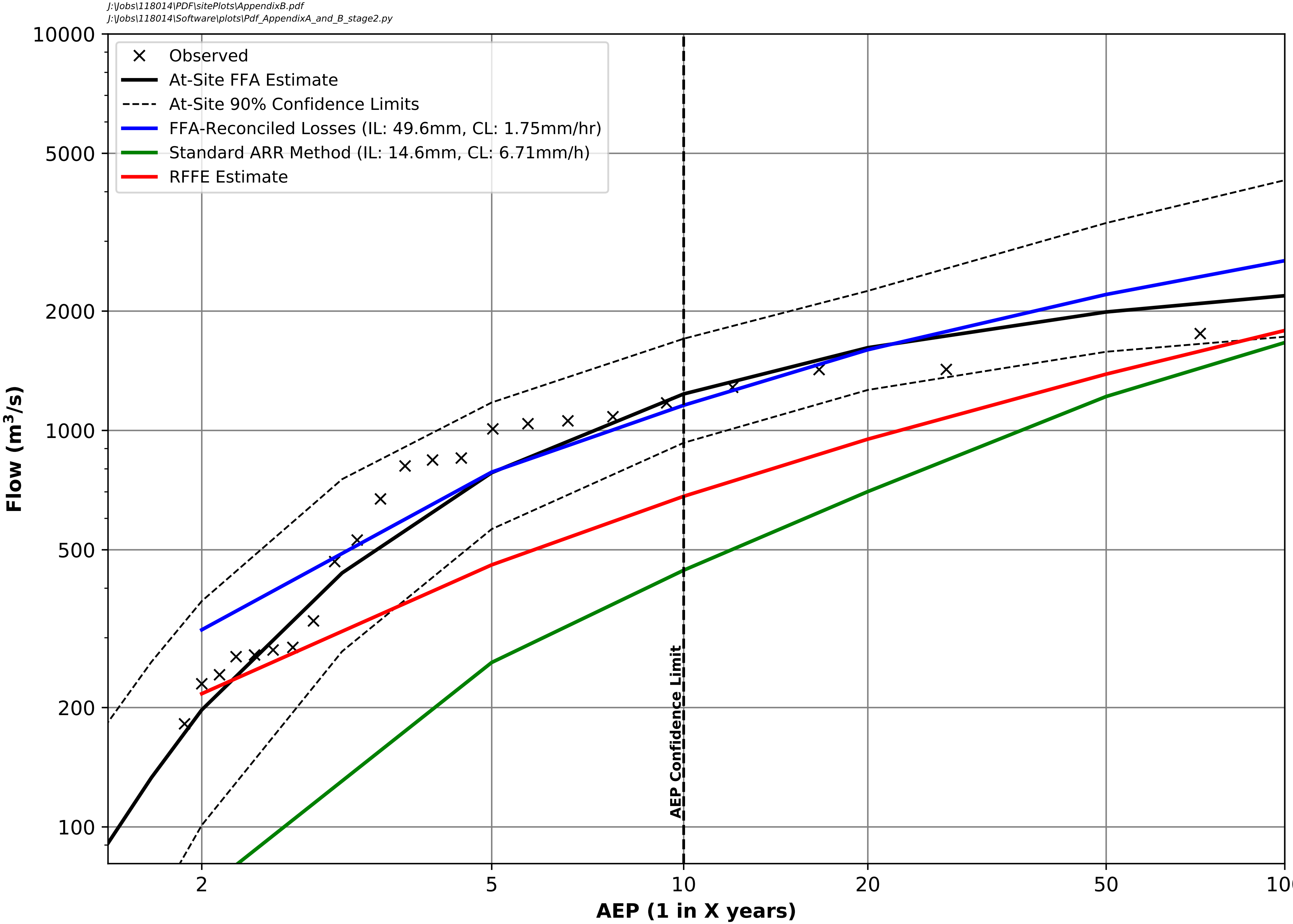


METHOD COMPARISON
NEW BUILDINGS BR - 220001 [A5]

APPENDIX B5



METHOD COMPARISON
ANGLEDALE - 219025 [A6]

APPENDIX B6

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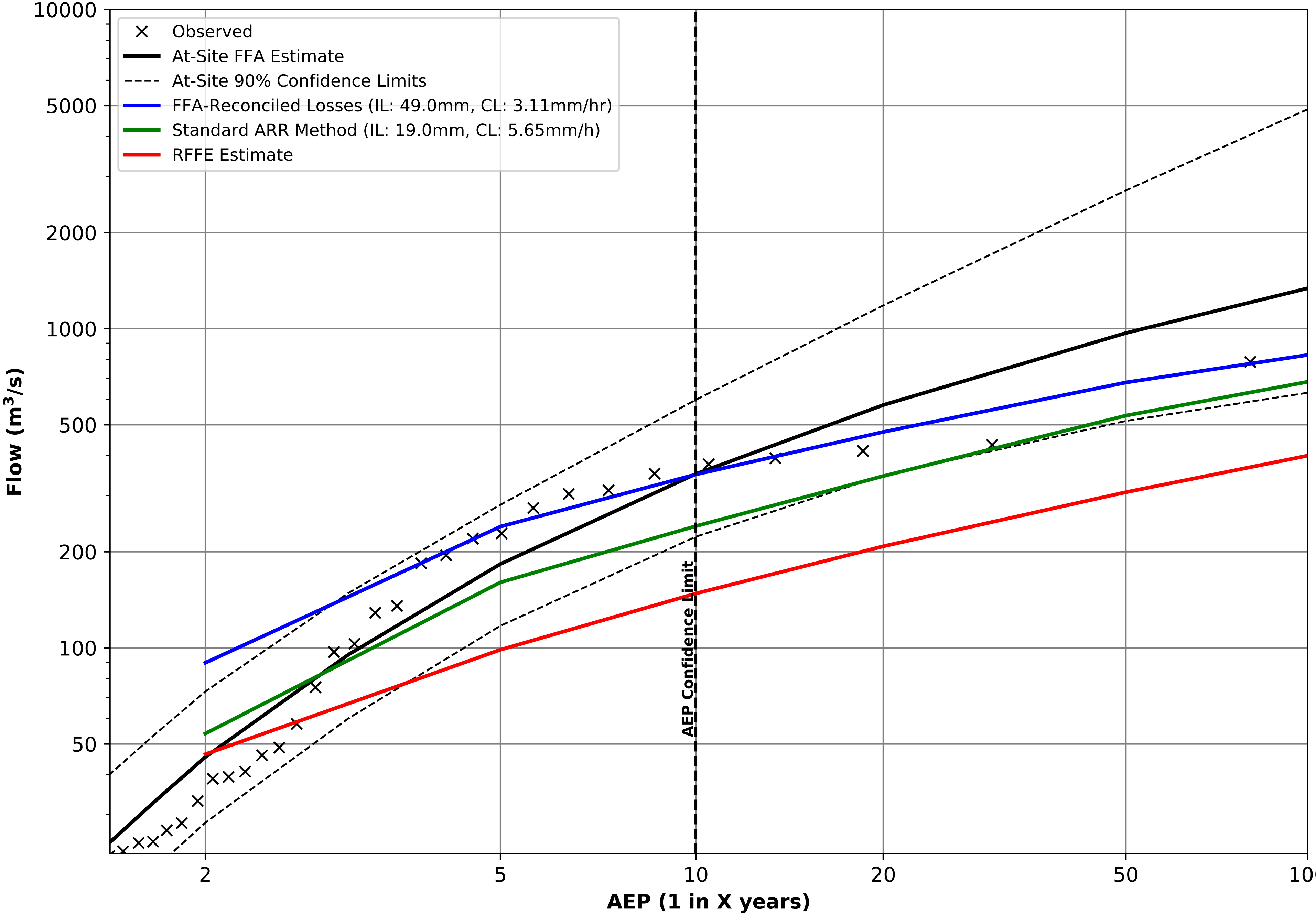
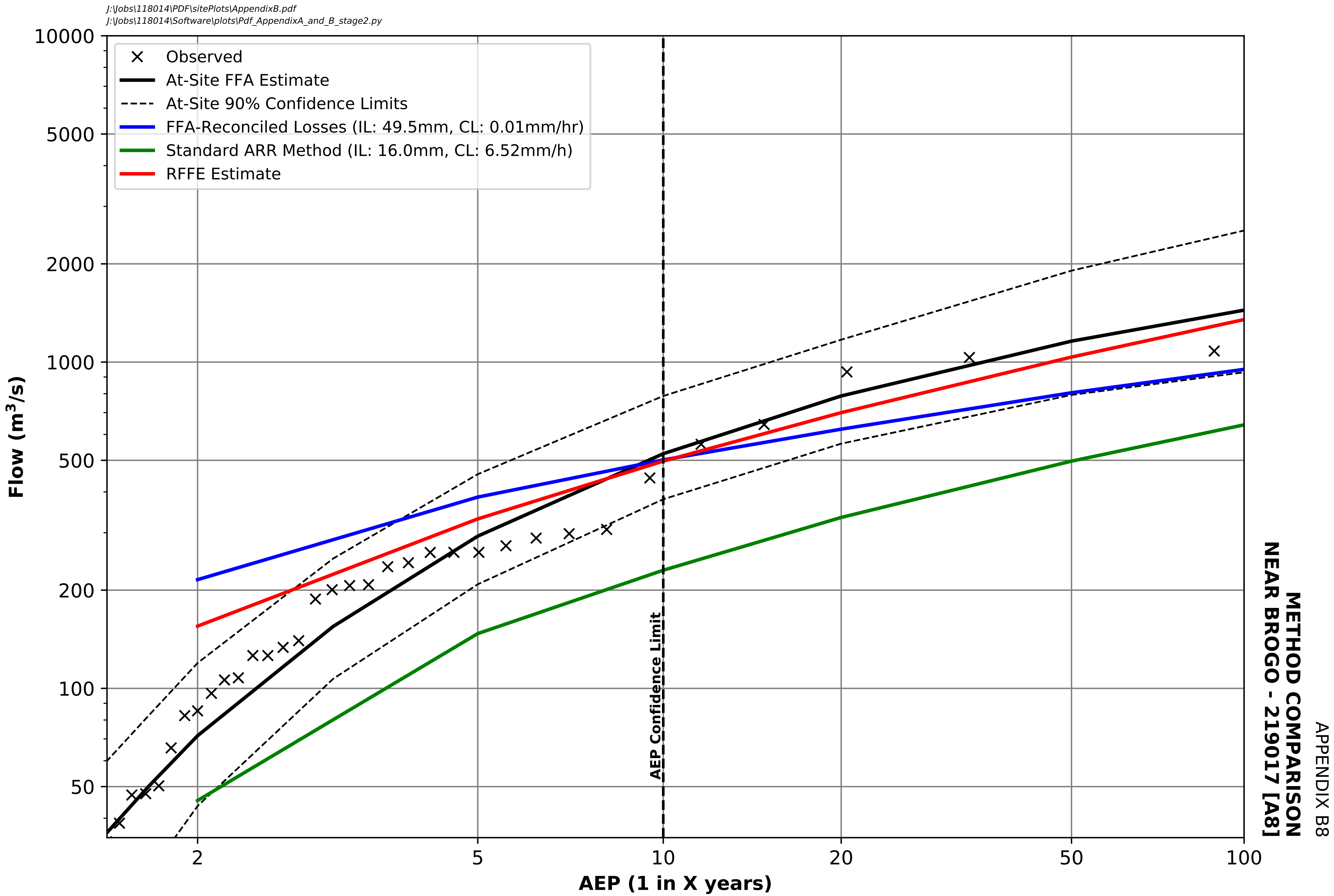


METHOD COMPARISON
CANDELO DAM SITE - 219022 [A7]

APPENDIX B7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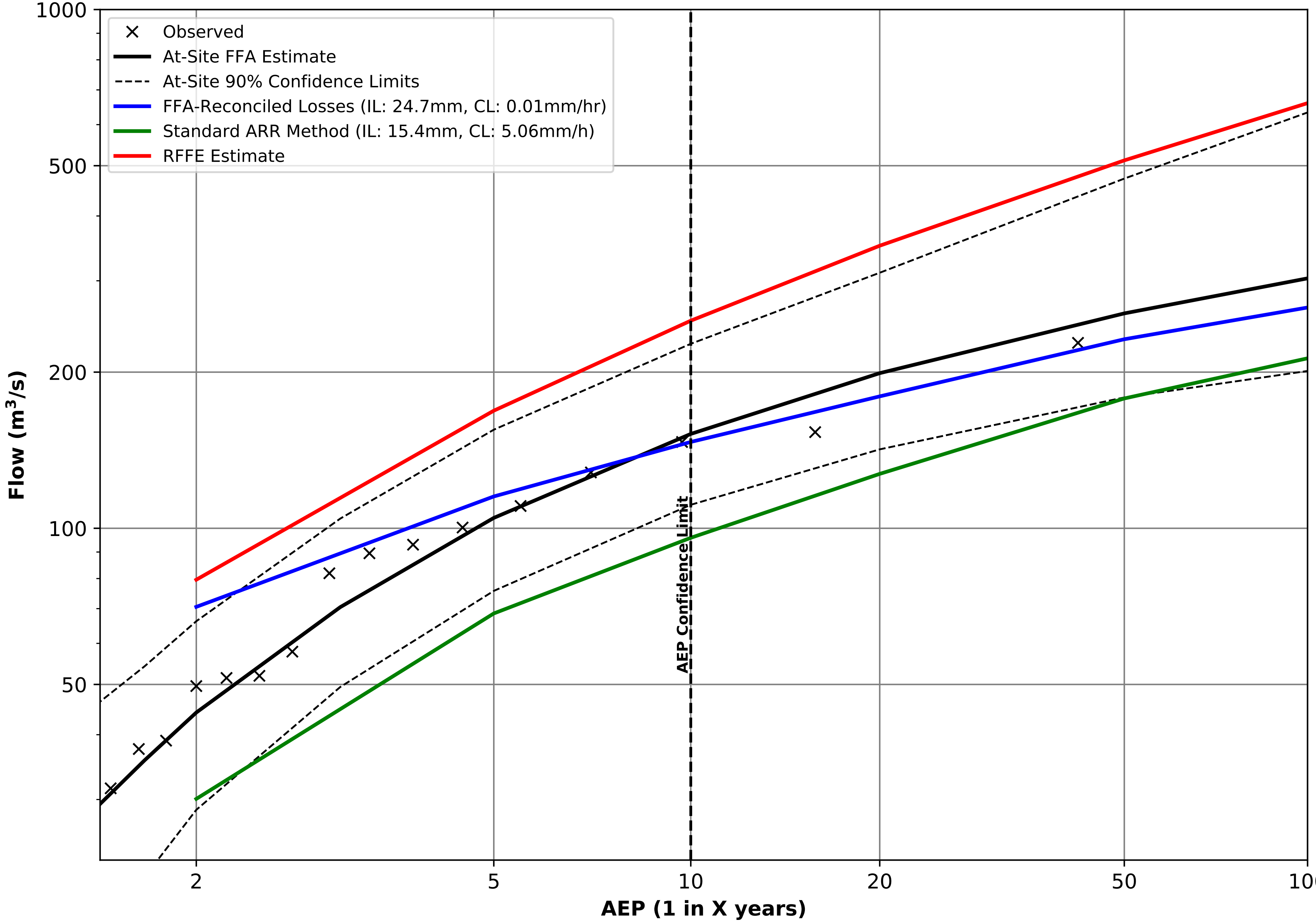
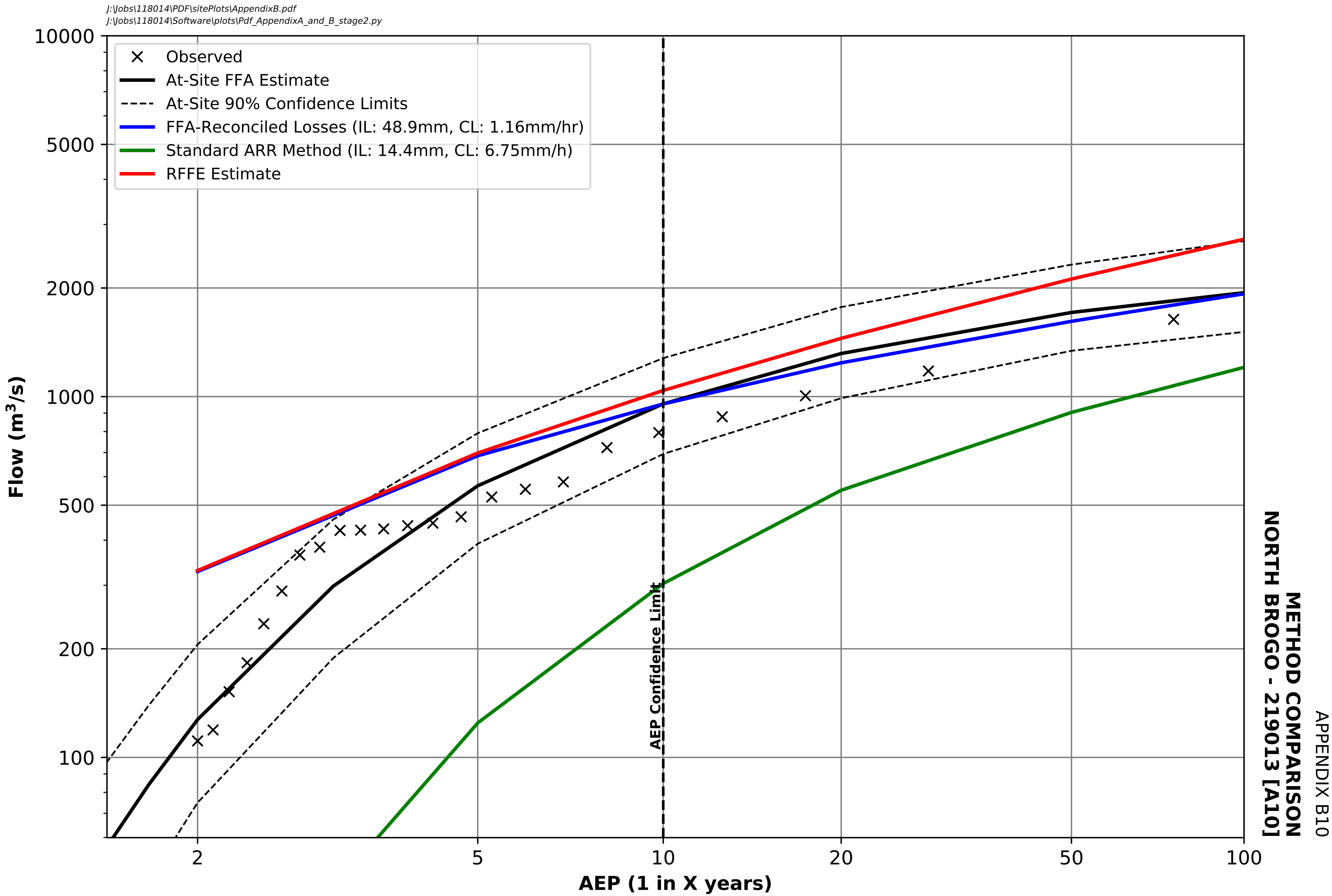
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 49.5mm, CL: 0.01mm/hr)
Standard ARR Method (IL: 16.0mm, CL: 6.52mm/h)
RFFE Estimate
Flow (m3/s)
10000
5000
2000
1000
500
200
100
50
AEP Confidence Limit
2
5
10
20
50
100
AEP (1 in X years)
METHOD COMPARISON
NEAR BROGO - 219017 [A8]
APPENDIX B8



METHOD COMPARISON
NEAR BERMAGUI - 219015 [A9]

APPENDIX B9


J:\Jobs\118014\PDF\sitePlots\AppendixB.pdf
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 48.9mm, CL: 1.16mm/hr)
Standard ARR Method (IL: 14.4mm, CL: 6.75mm/h)
RFFE Estimate
AEP Confidence Limit
Flow (m3/s)
AEP (1 in X years)
10000
5000
2000
1000
500
200
100
2
5
10
20
50
100
METHOD COMPARISON
NORTH BROGO - 219013 [A10]
APPENDIX B10

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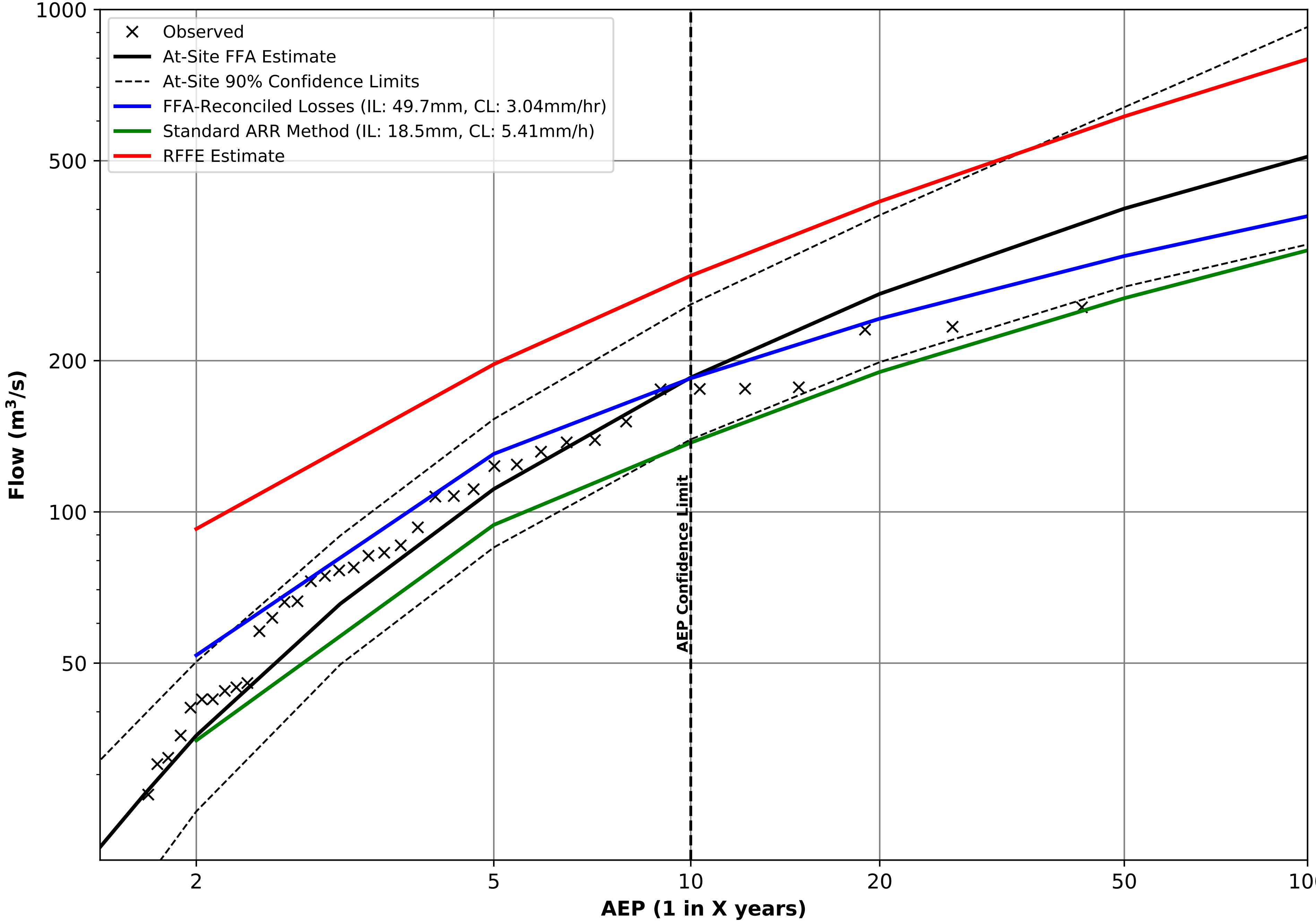
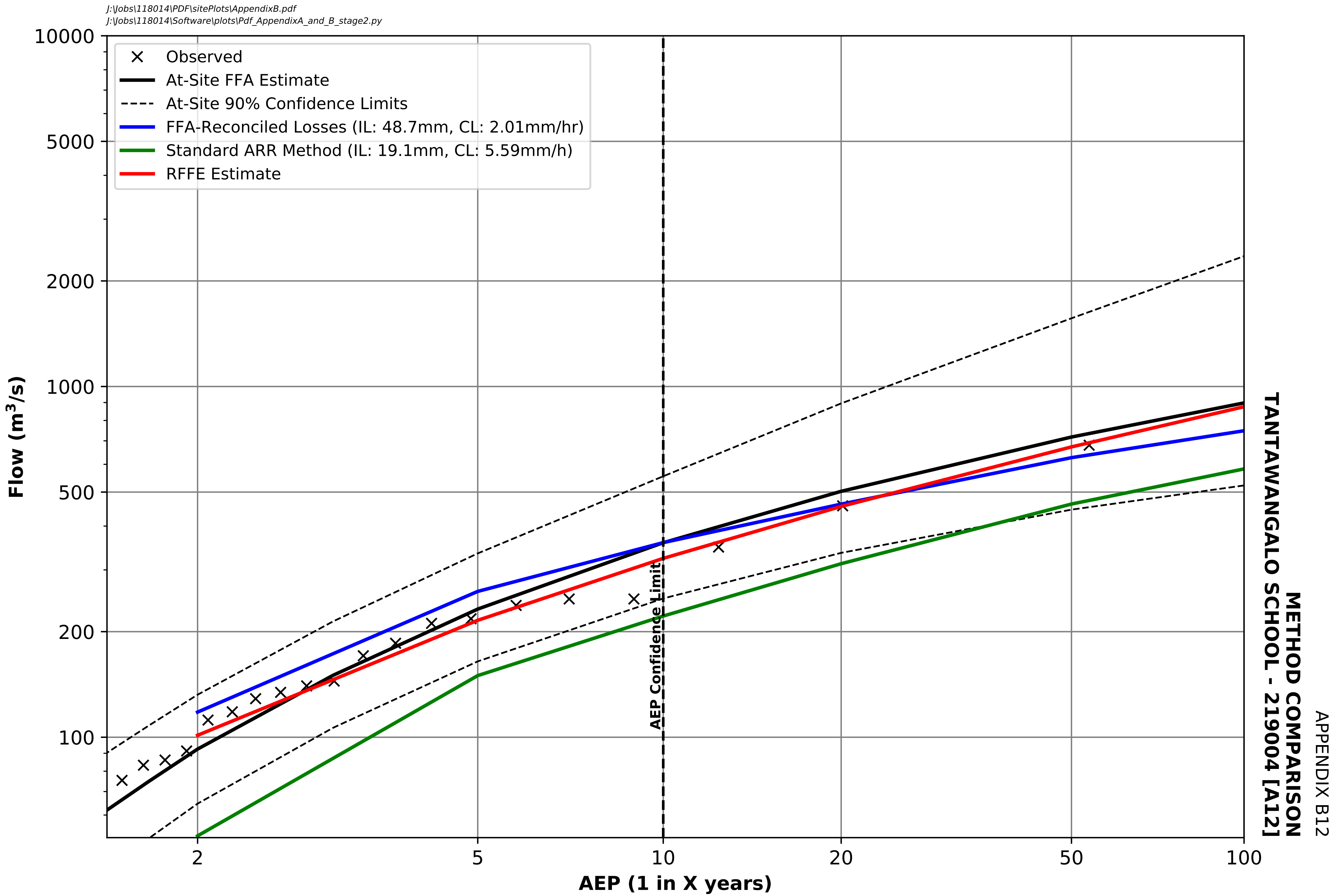


METHOD COMPARISON
TANTAWANGALO MOUNTAIN (DAM) - 219006 [A11]

APPENDIX B11



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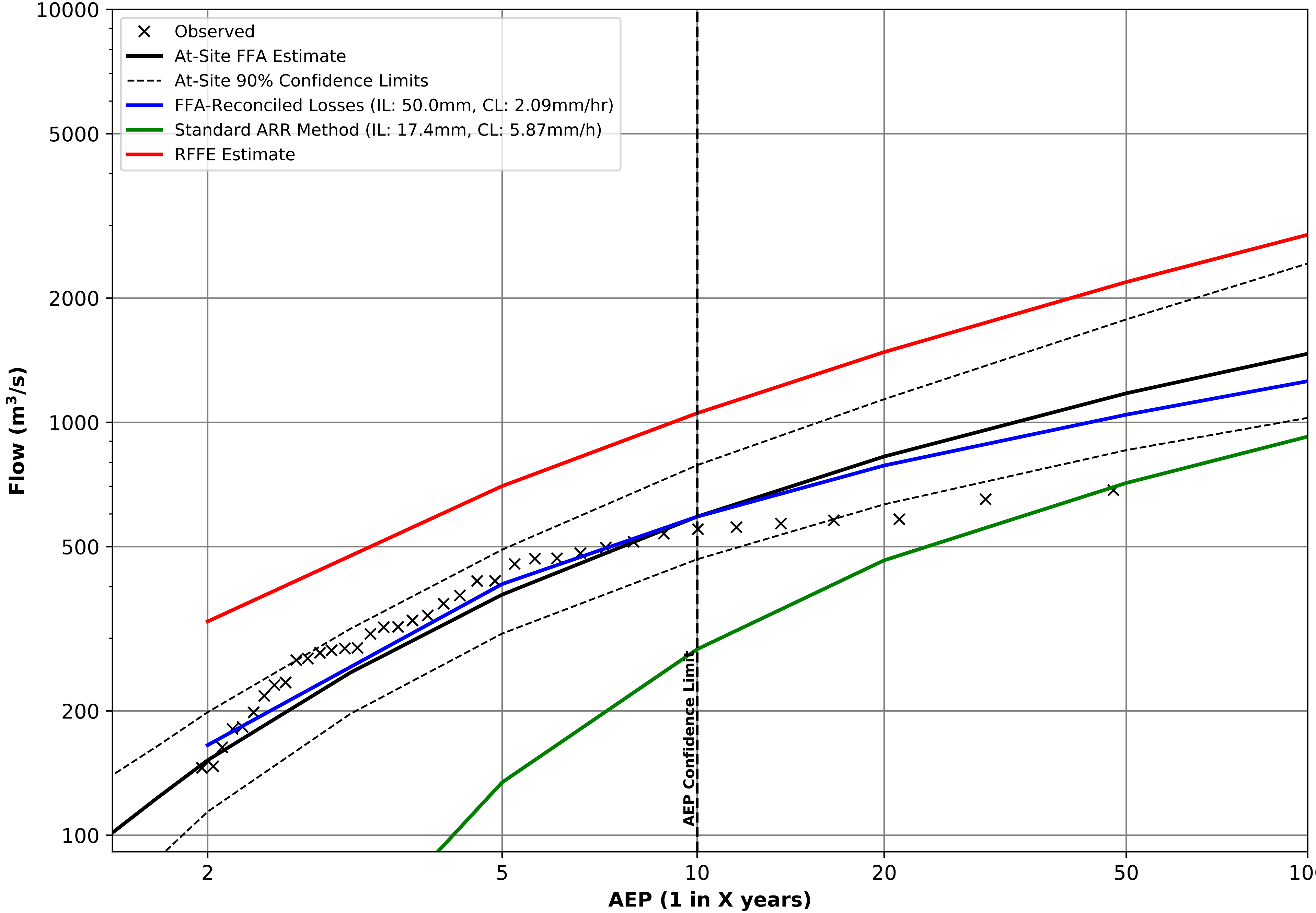
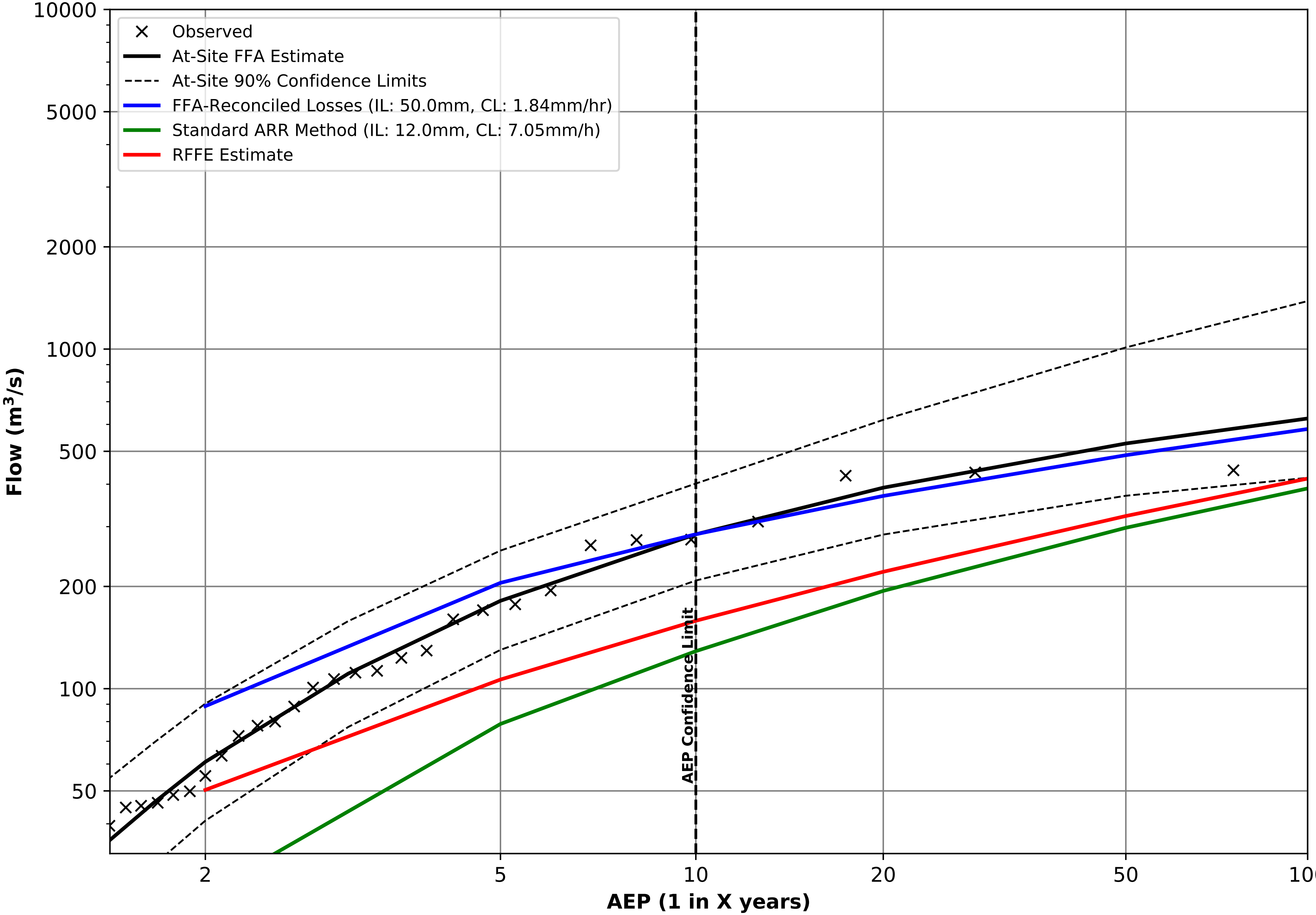
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 48.7mm, CL: 2.01mm/hr)
Standard ARR Method (IL: 19.1mm, CL: 5.59mm/h)
RFFE Estimate
AEP Confidence Limit
Flow (m³/s)
10000
5000
2000
1000
500
200
100
2
5
10
20
50
100
AEP (1 in X years)
METHOD COMPARISON
TANTAWANGALO SCHOOL - 219004 [A12]
APPENDIX B12



METHOD COMPARISON
MORANS CROSSING - 219003 [A13]

APPENDIX B13



METHOD COMPARISON
WADBILLIGA - 218007 [A14]

APPENDIX B14

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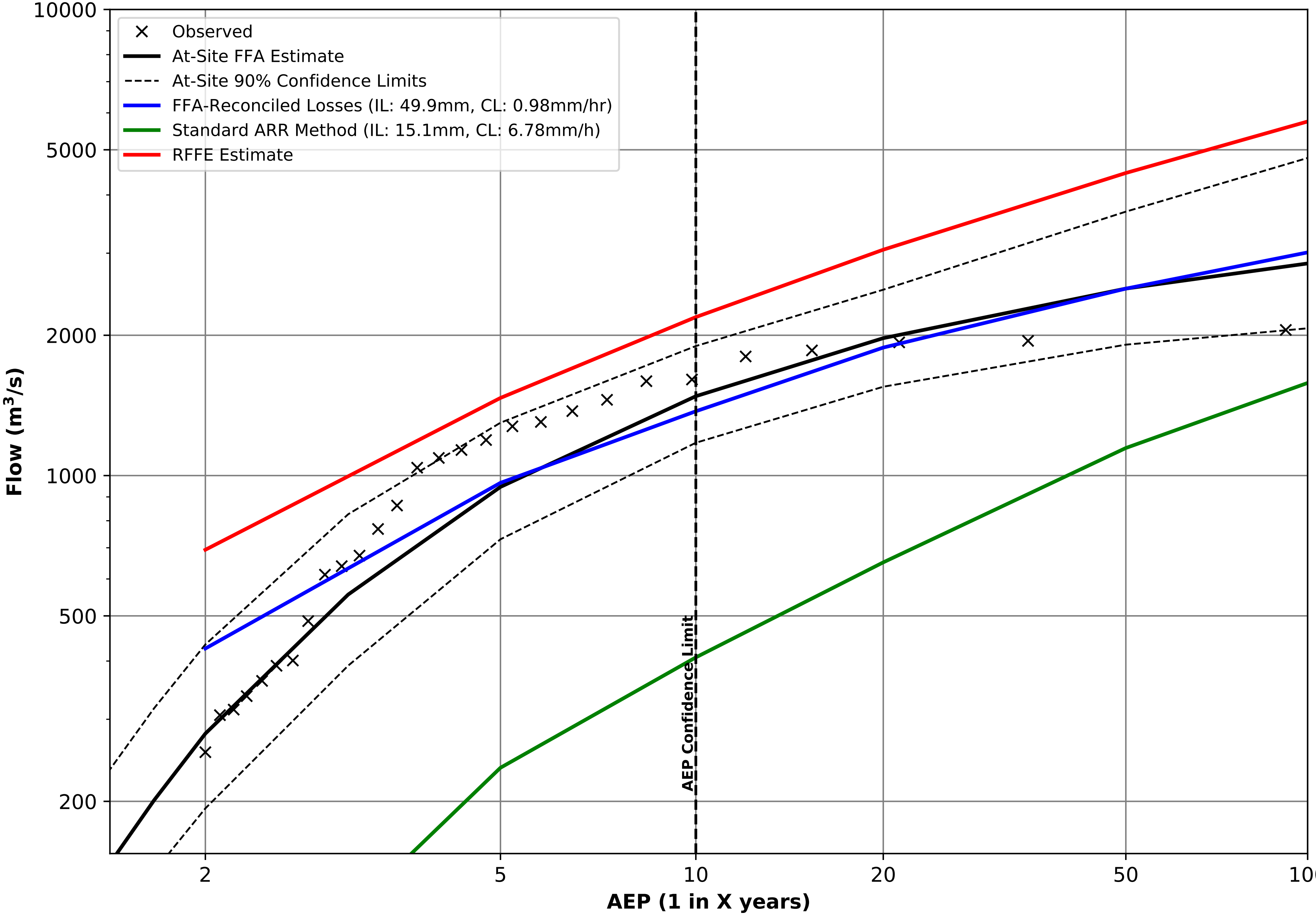
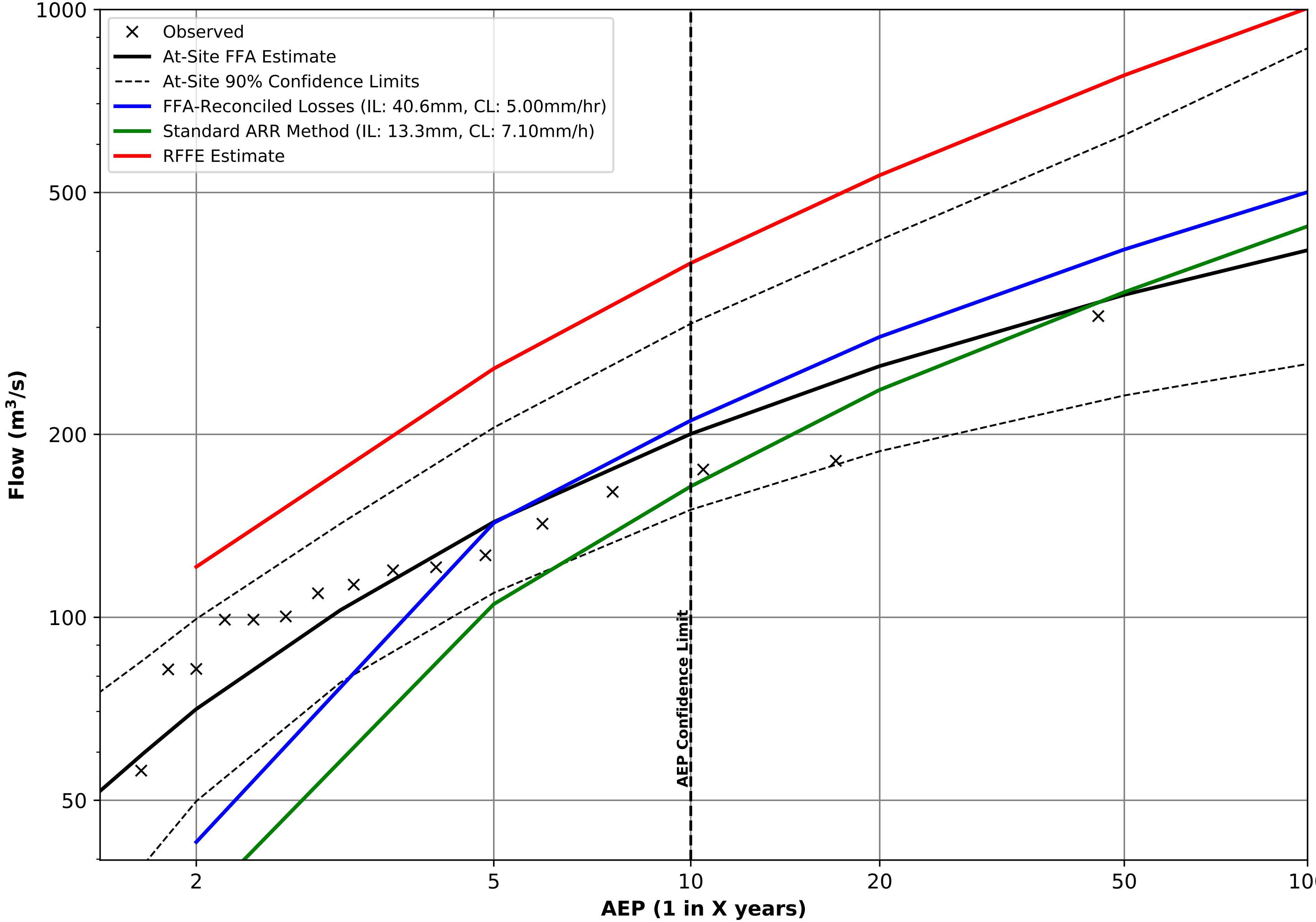


METHOD COMPARISON

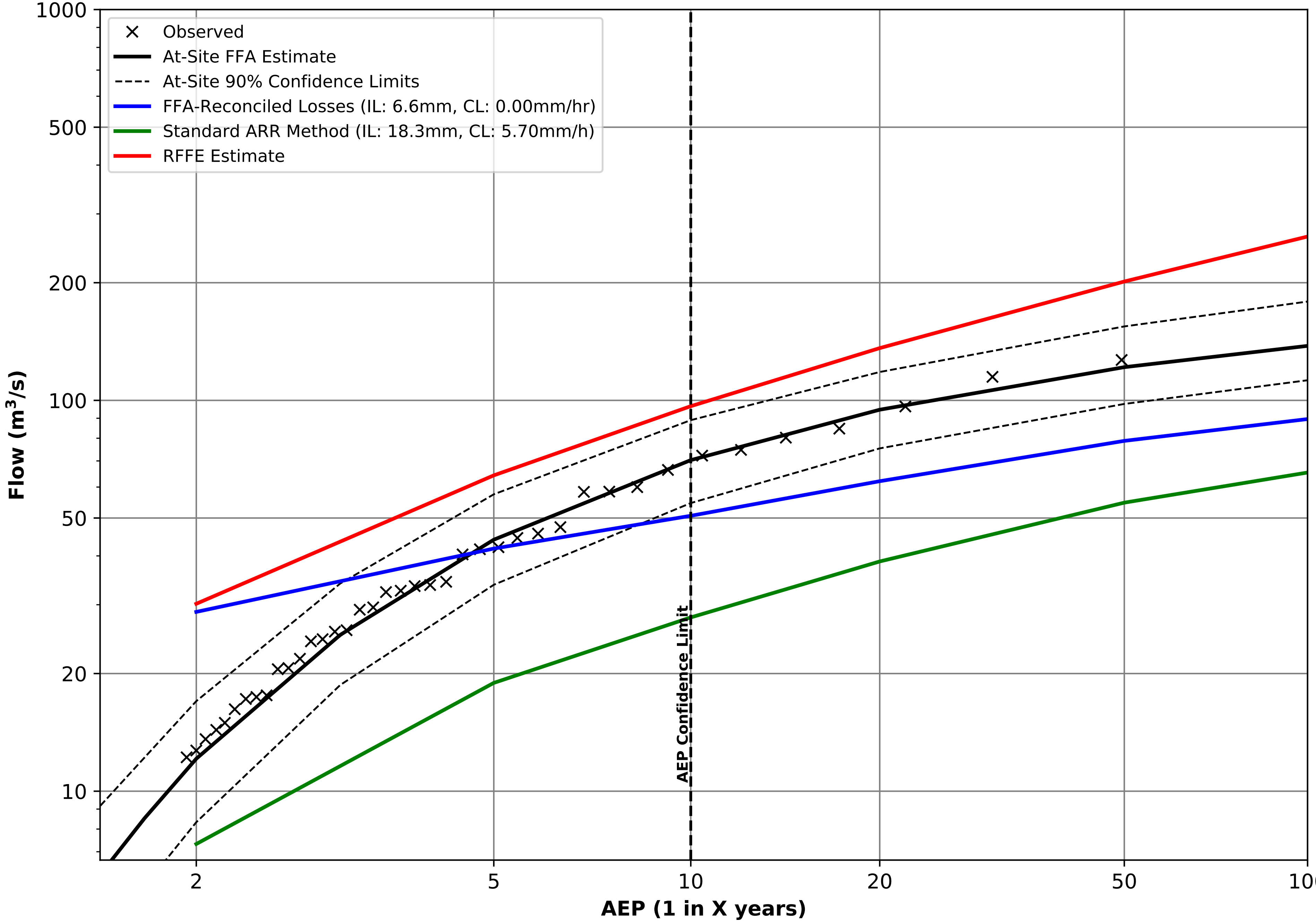
D/S WADBILLIGA R JUNCT - 218005 [A15]

APPENDIX B15



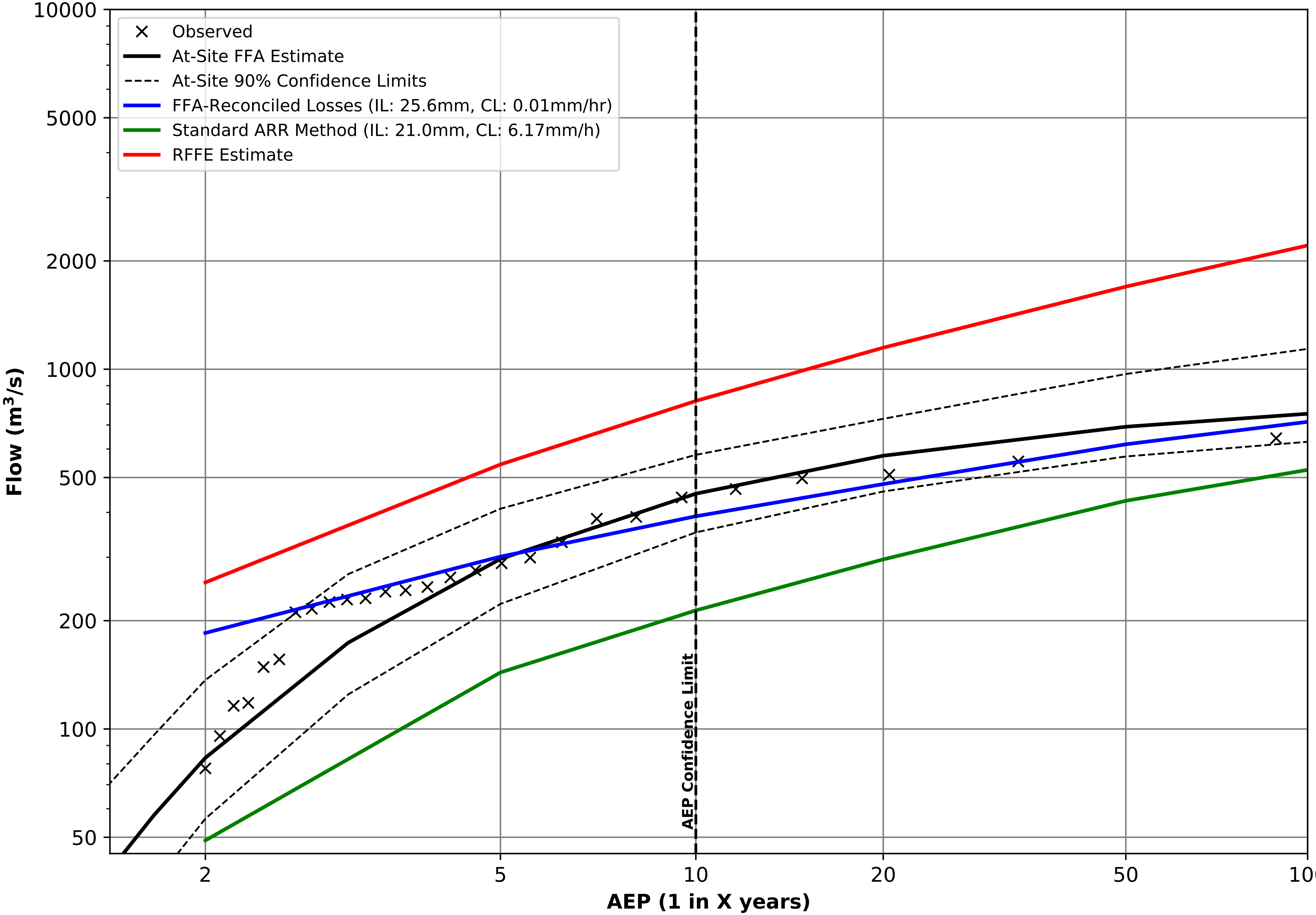
METHOD COMPARISON
YOWRIE - 218003 [A16]

APPENDIX B16



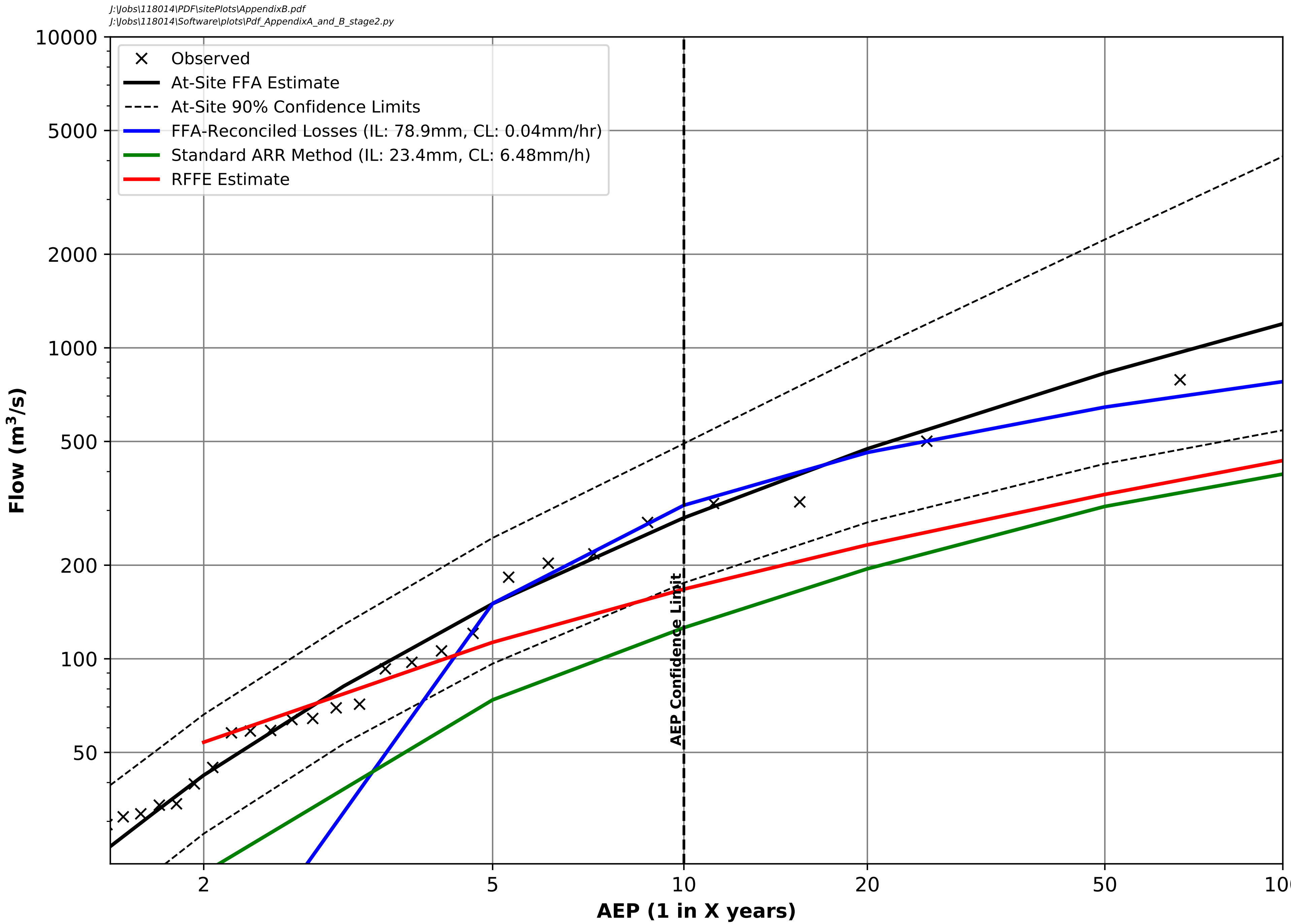
METHOD COMPARISON
BROWN MOUNTAIN - 219001 [A17]

APPENDIX B17



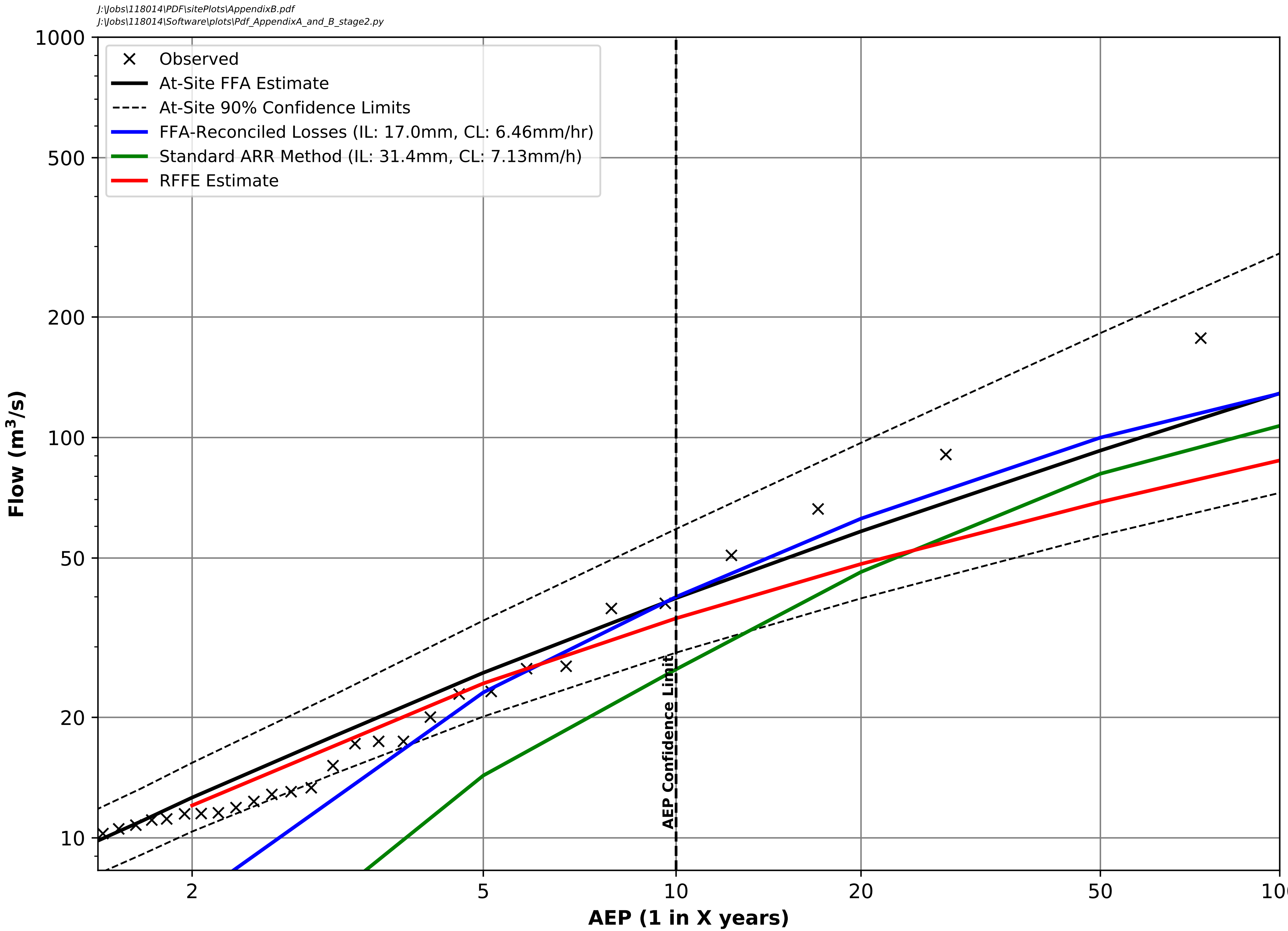
METHOD COMPARISON
LOCHIEL - 220003 [A18]

APPENDIX B18



METHOD COMPARISON
THE HUT - 222017 [B1]

APPENDIX B19



METHOD COMPARISON
THE BARRY WAY - 222016 [B2]

APPENDIX B20

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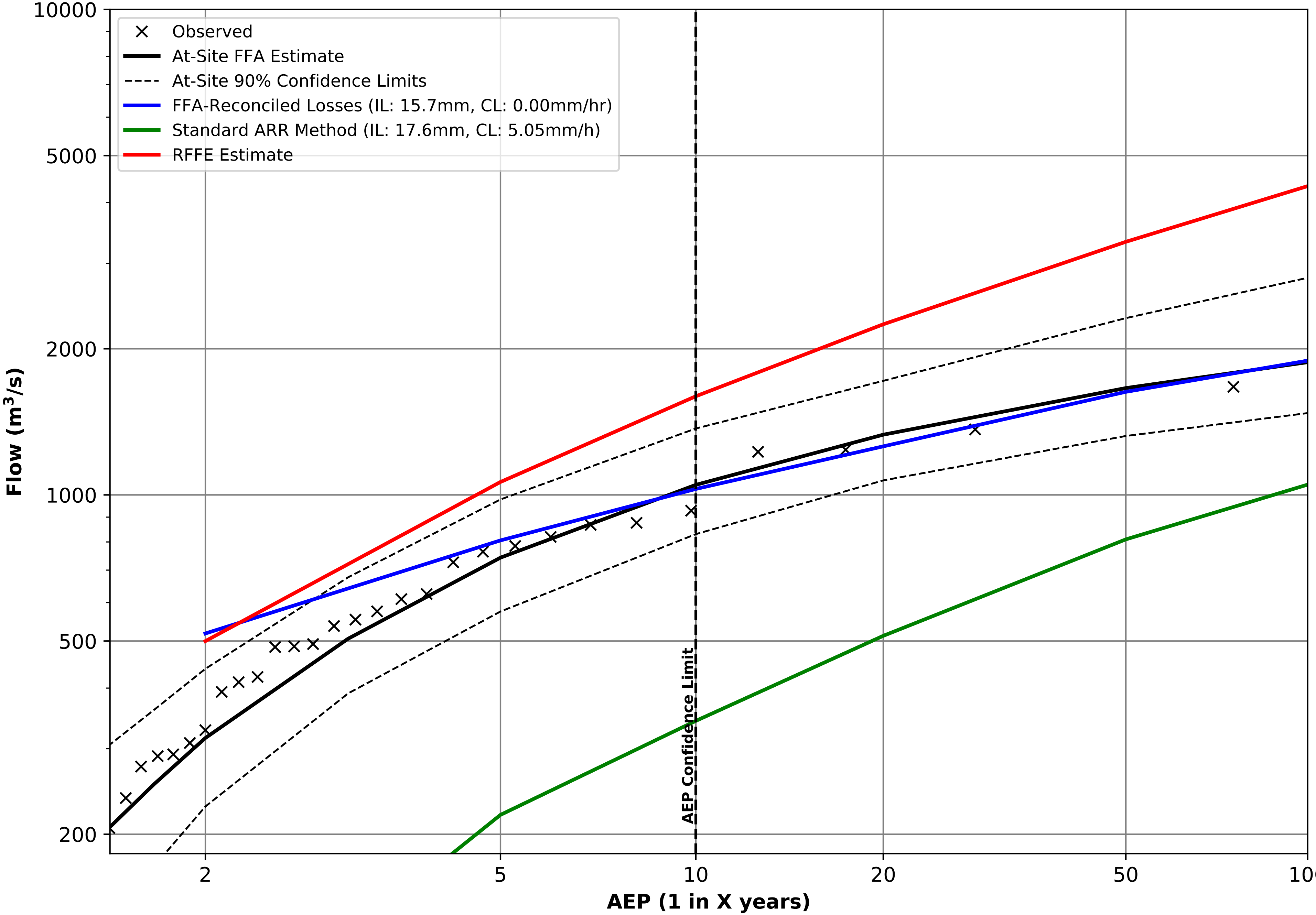
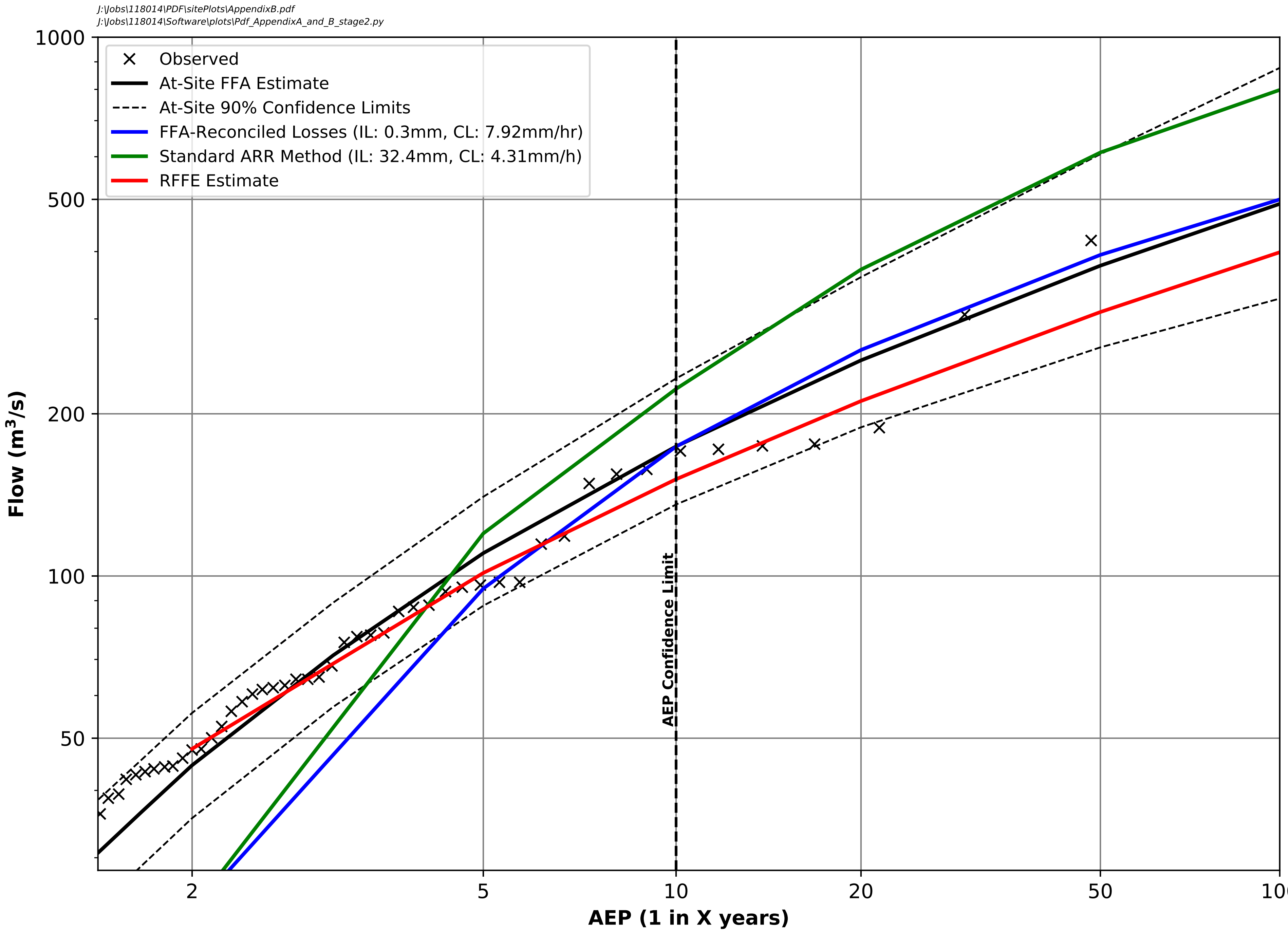


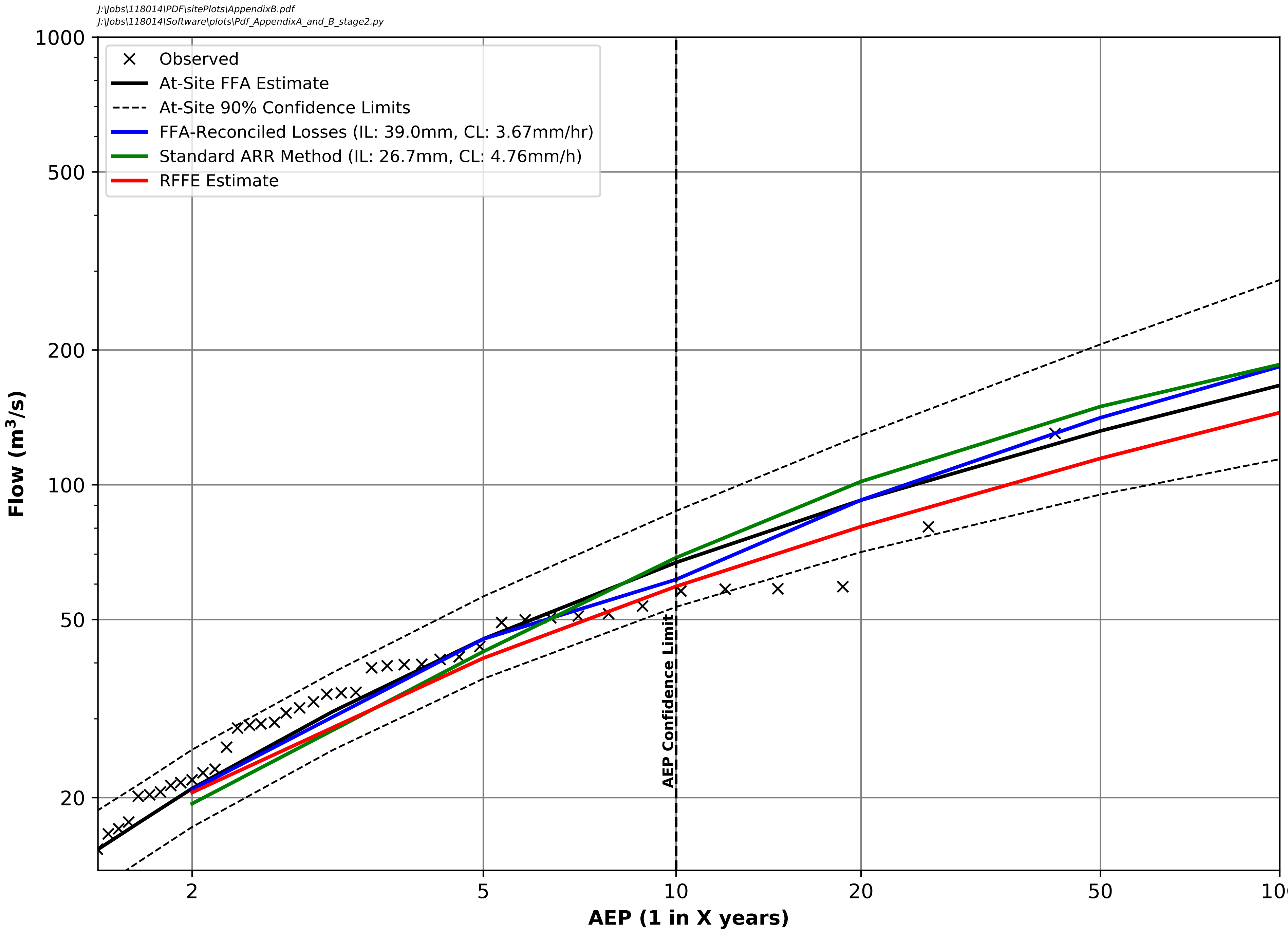
METHOD COMPARISON
THE FALLS - 222009 [B3]

APPENDIX B21



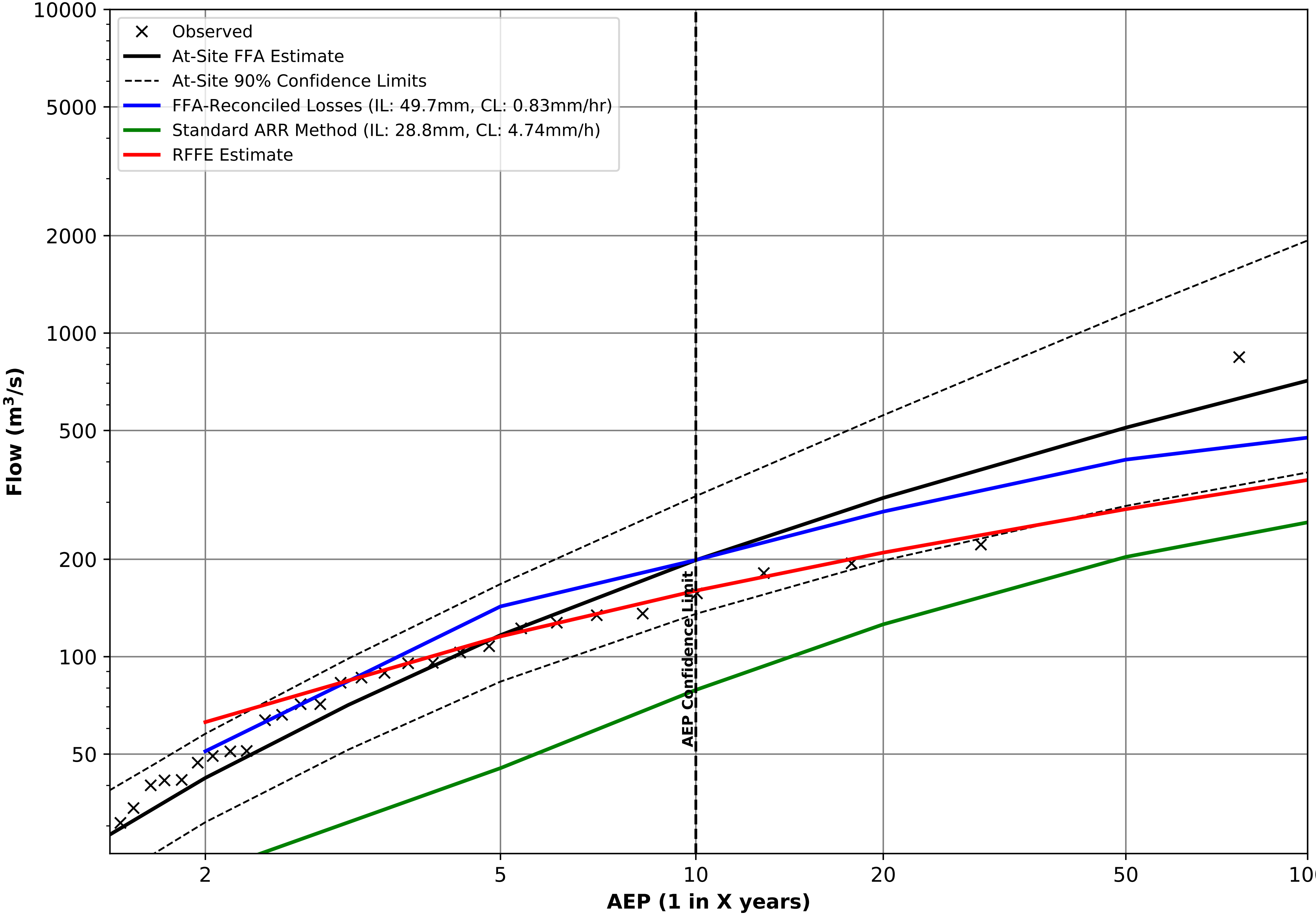
METHOD COMPARISON
WELLESLEY (ROWES) - 222004 [B4]

APPENDIX B22



METHOD COMPARISON
MARAGLE - 401009 [C2]

APPENDIX B23



METHOD COMPARISON
JINGELLIC - 401013 [C3]

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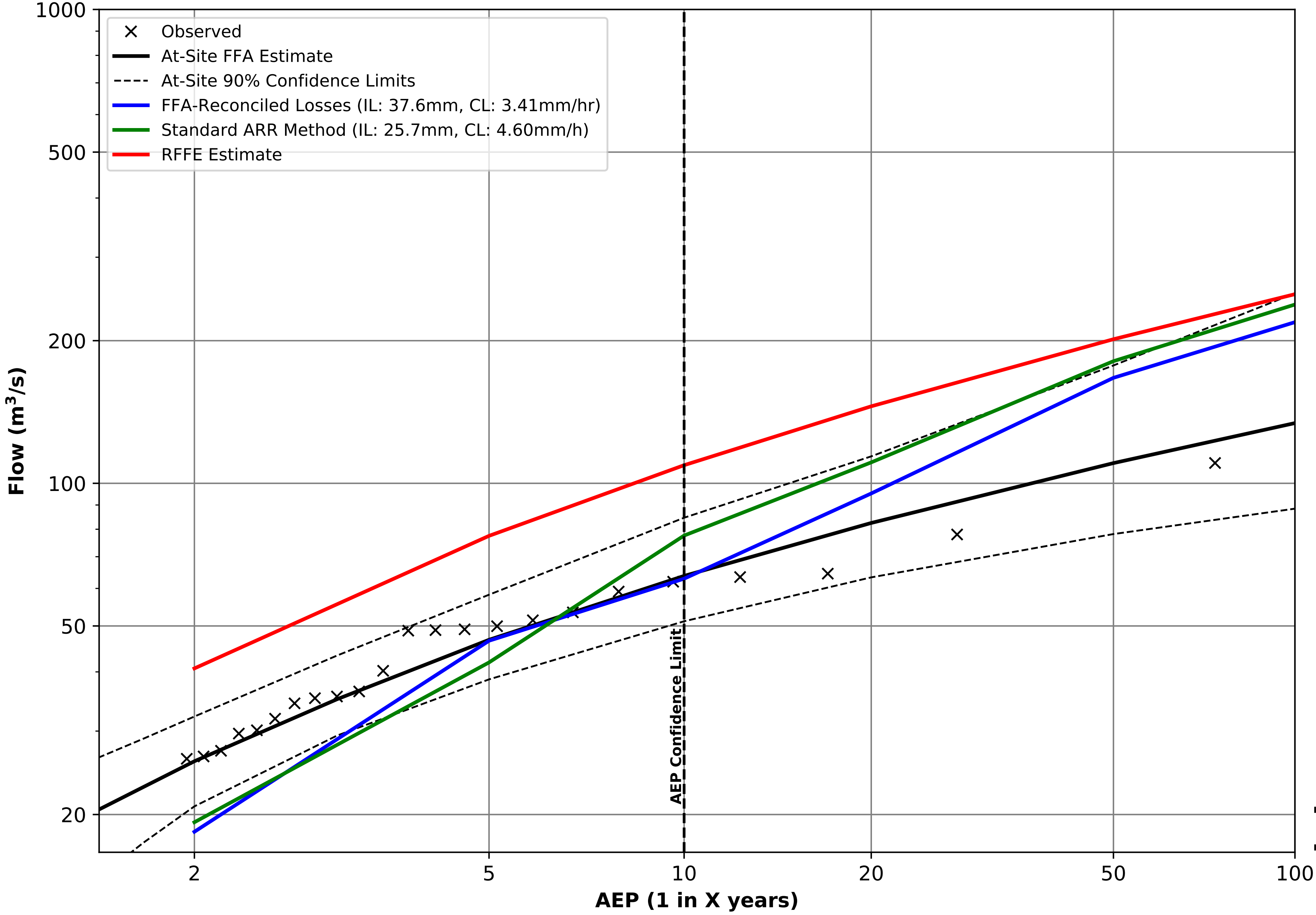
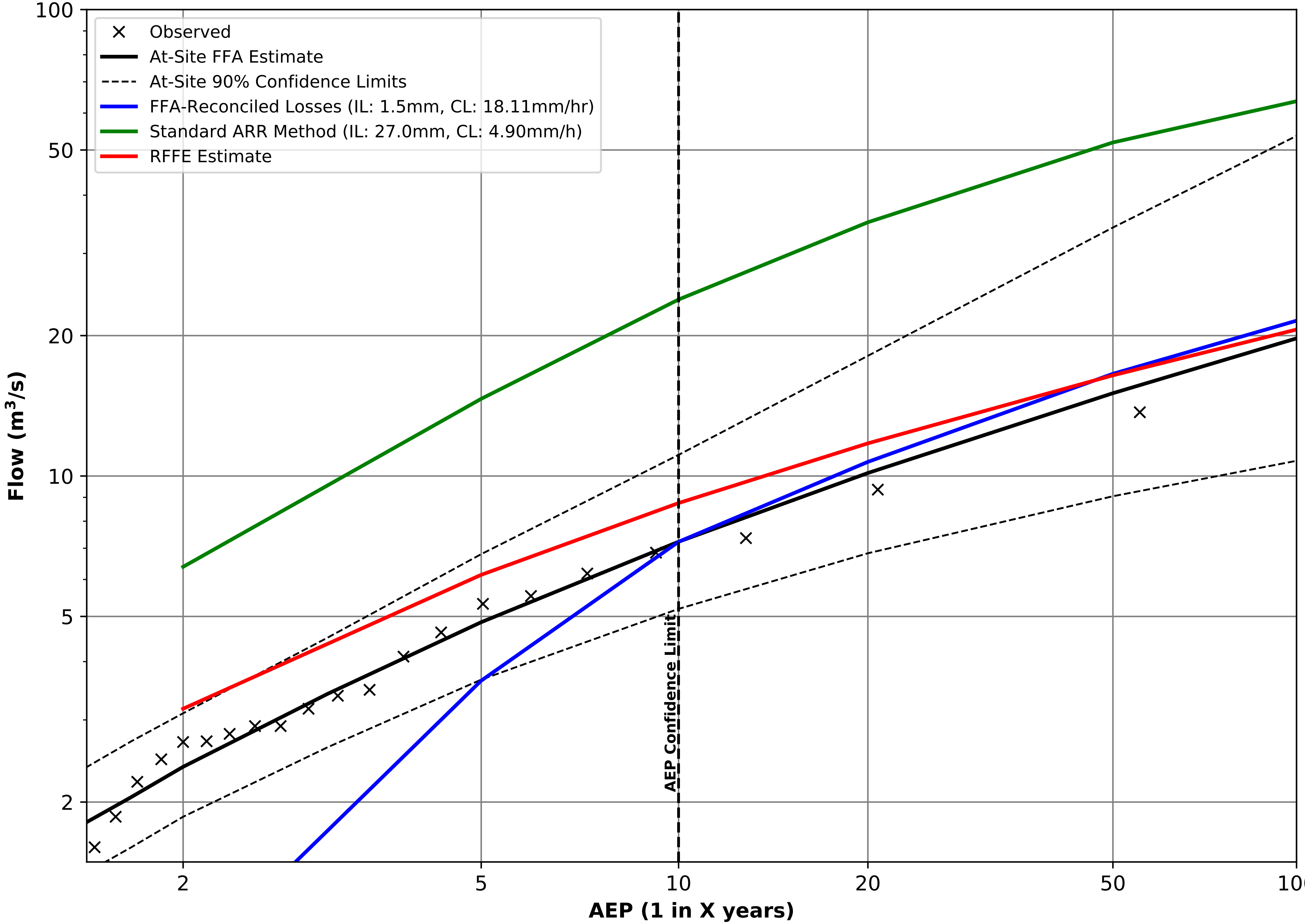


METHOD COMPARISON
YAMBLA - 401015 [C4]

APPENDIX B25



METHOD COMPARISON
THE SQUARE - 401016 [C5]

APPENDIX B26

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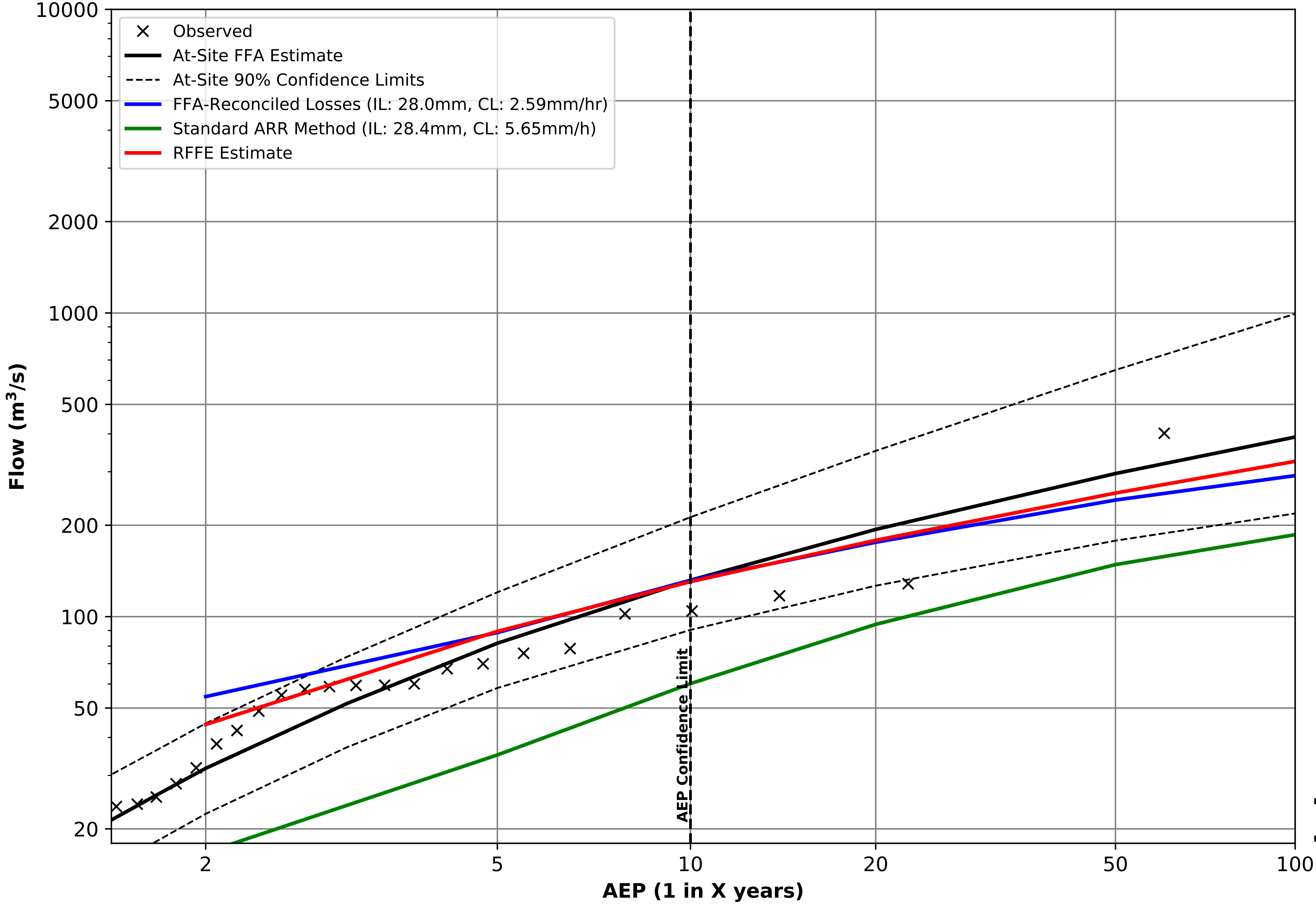

METHOD COMPARISON
YARRAMUNDI - 401017 [C6]

APPENDIX B27

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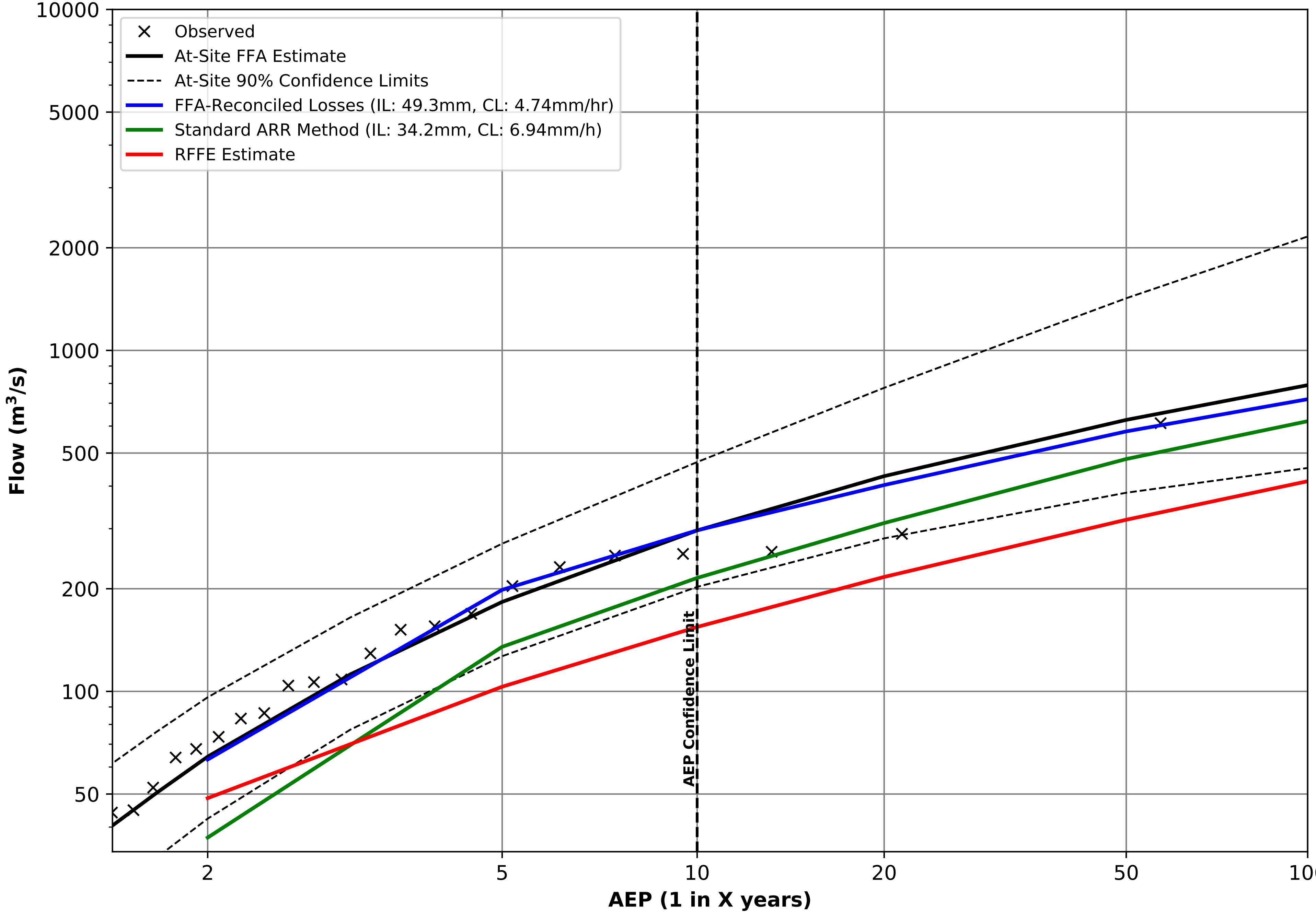
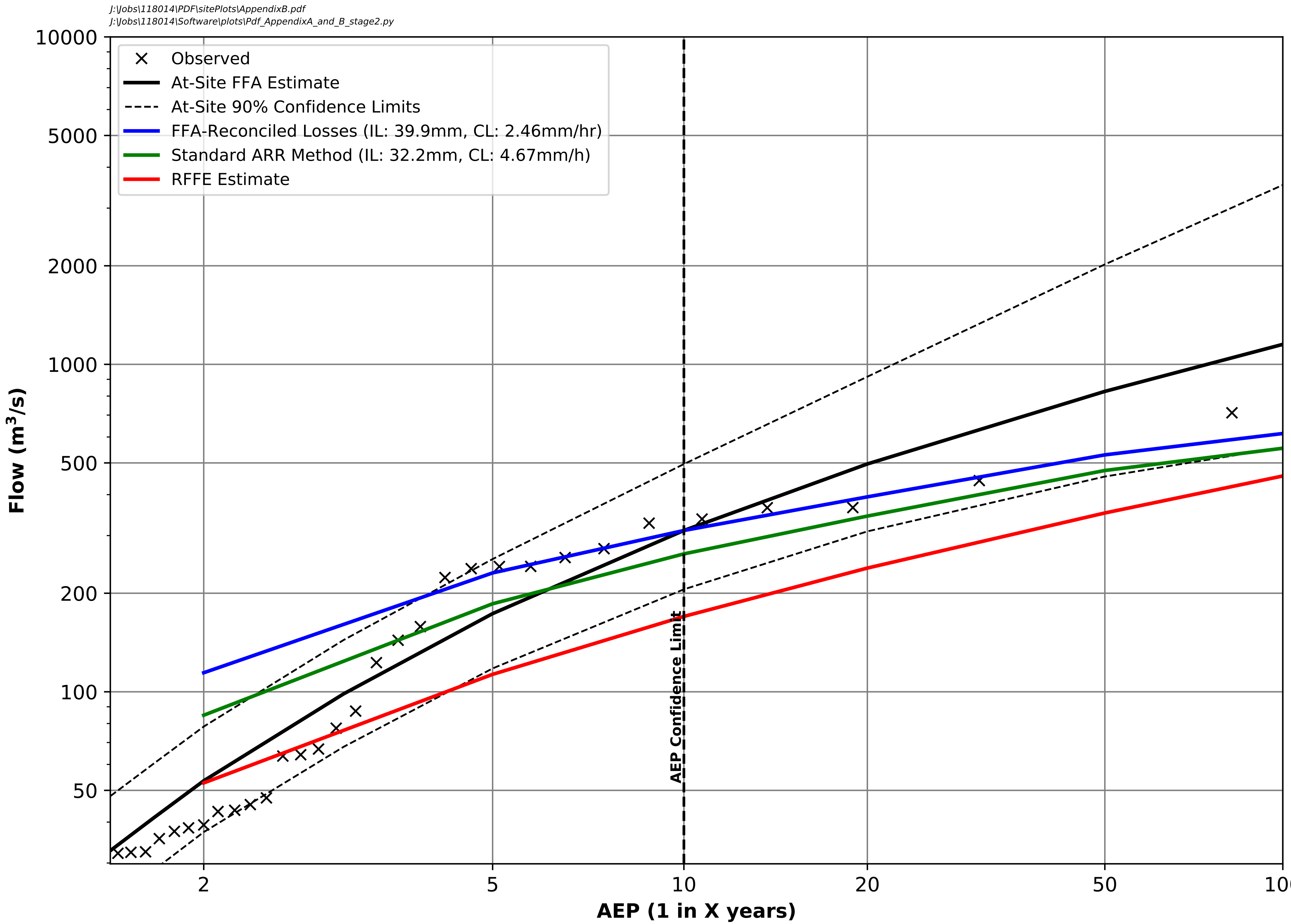


METHOD COMPARISON
BUCKENBOWRA NO.3 - 216009 [D1]

APPENDIX B28



METHOD COMPARISON
FALLS CK - 216004 [D3]

APPENDIX B29

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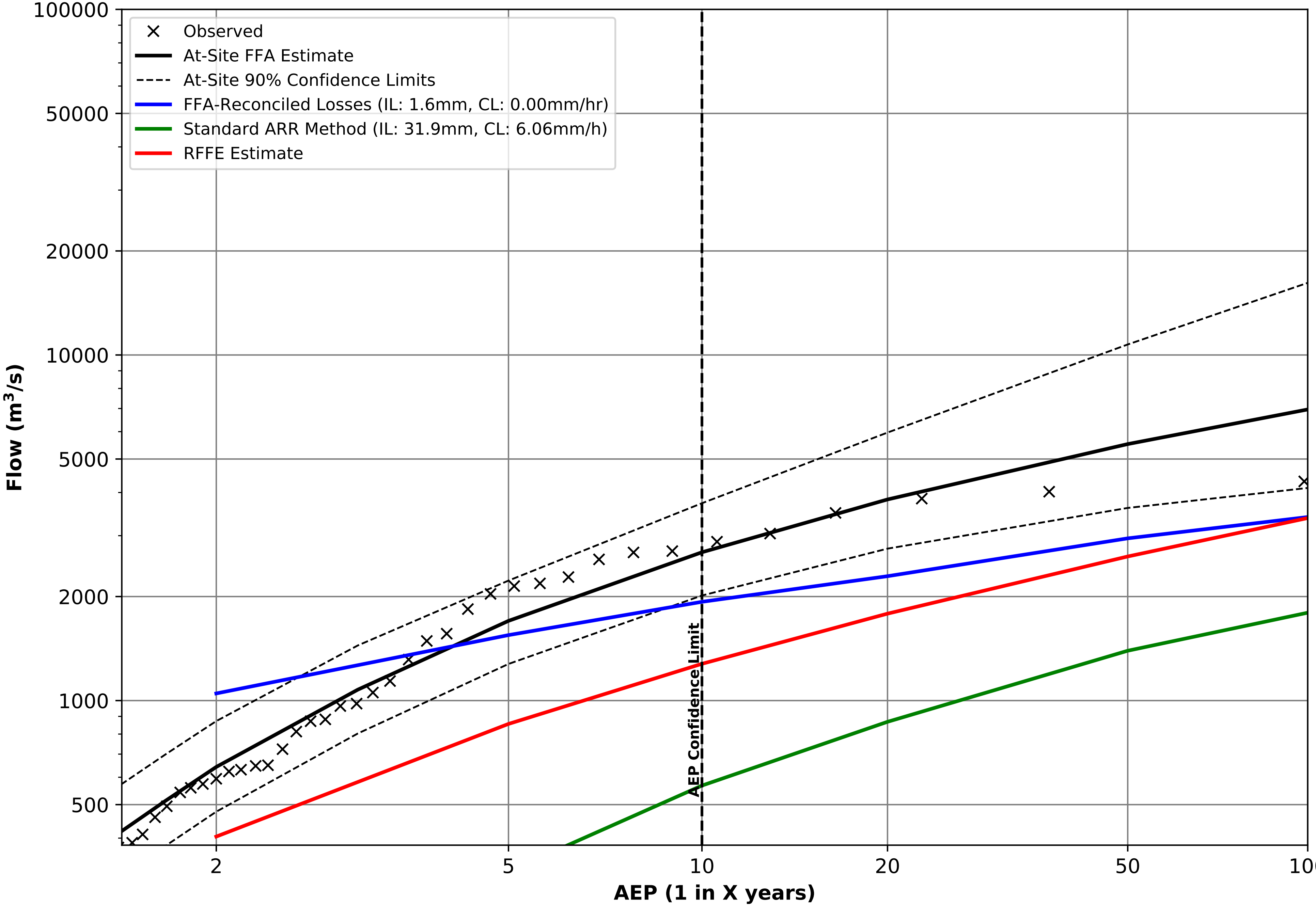
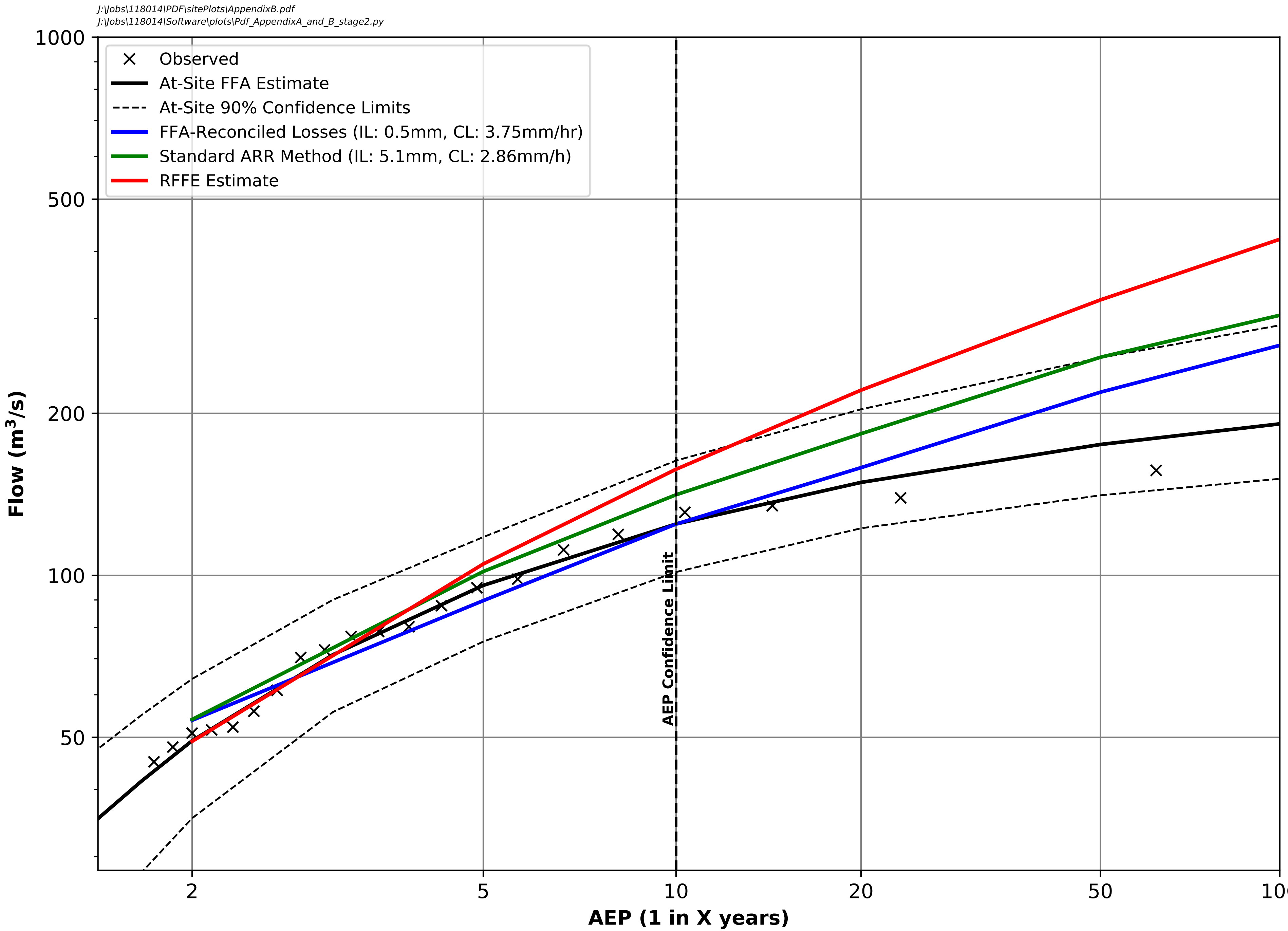


METHOD COMPARISON
BROOMAN - 216002 [D4]

APPENDIX B30



METHOD COMPARISON
BUNGONIA - 215014 [D5]

APPENDIX B31

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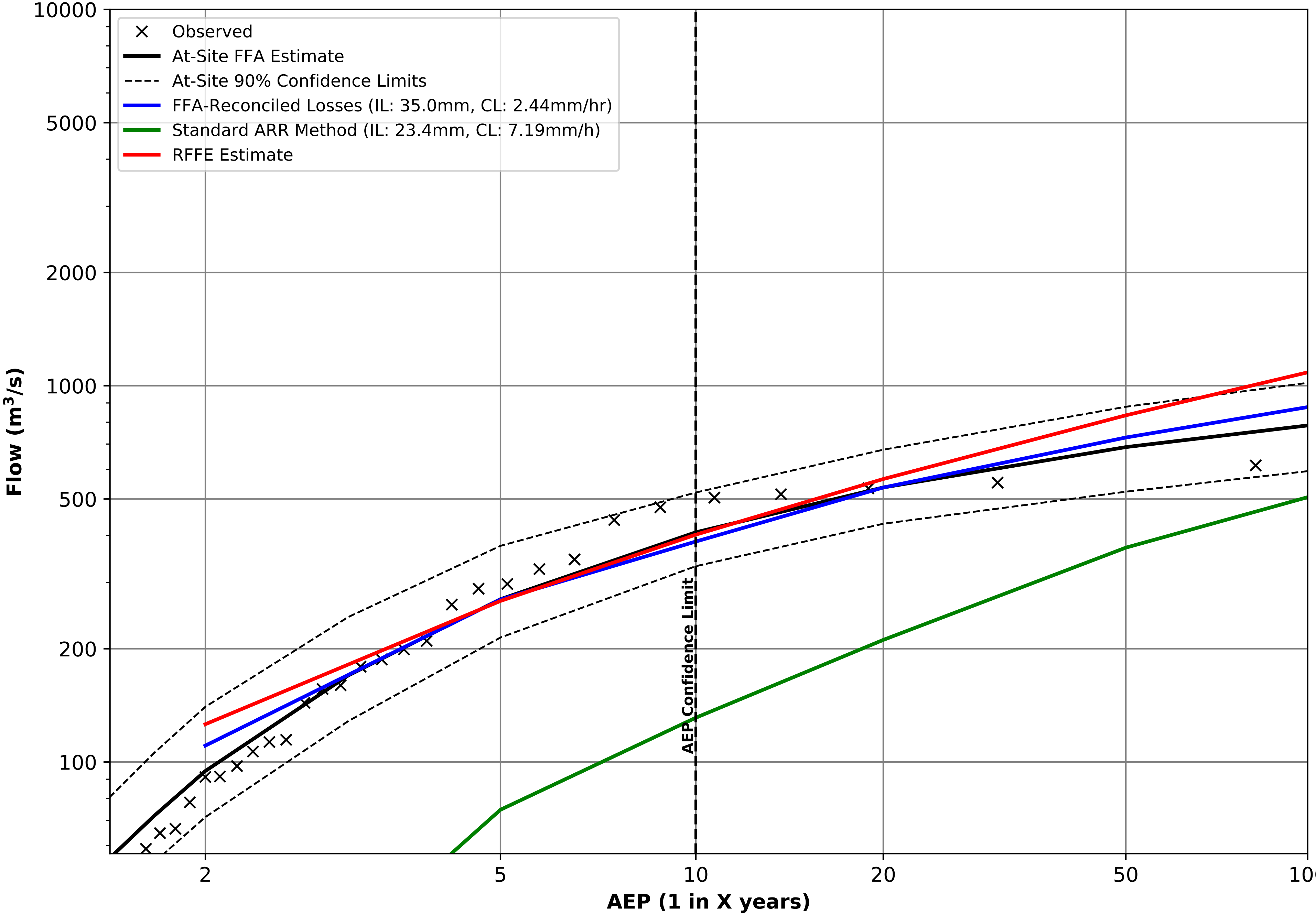

METHOD COMPARISON
KADOONA - 215008 [D6]

APPENDIX B32

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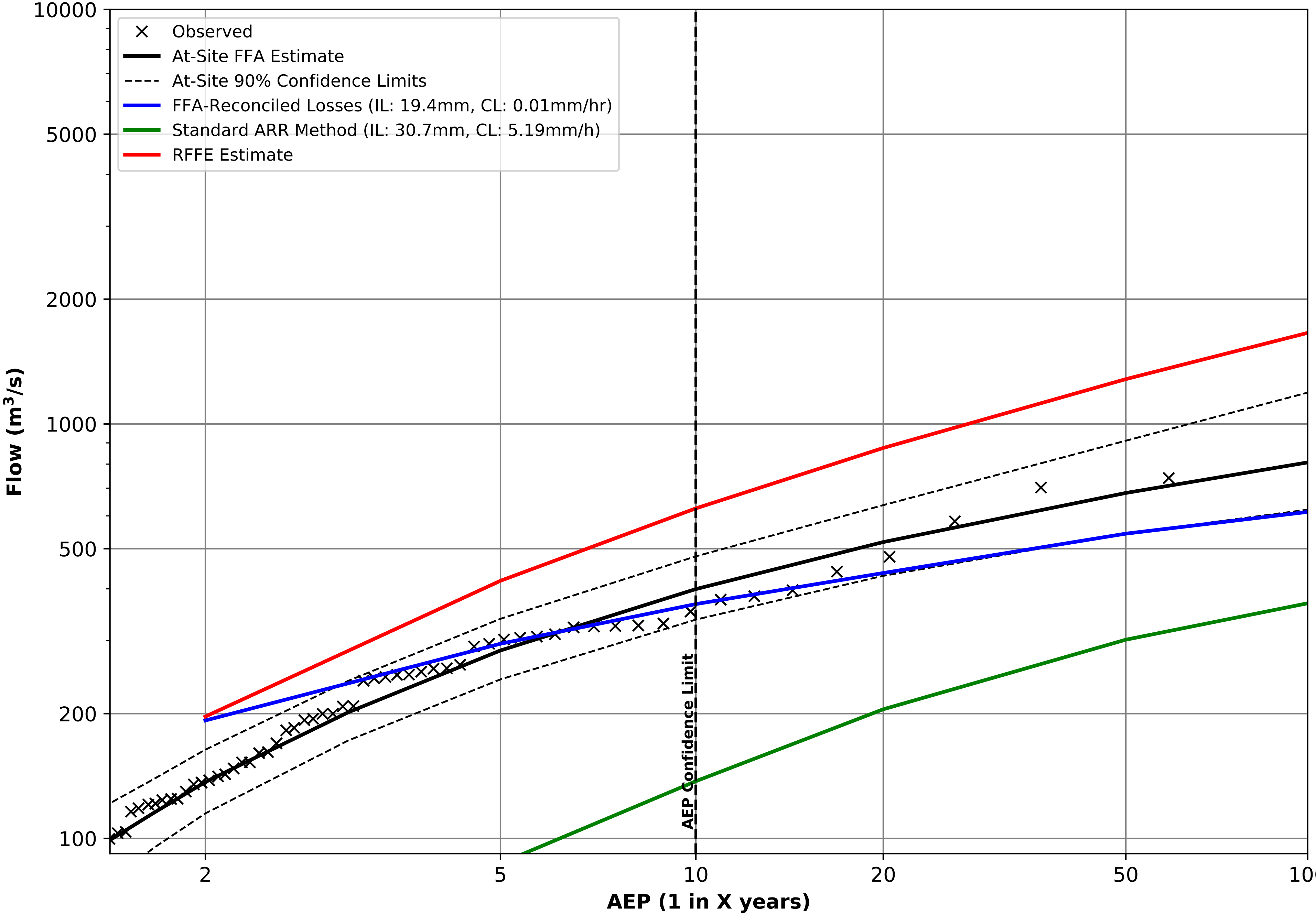

METHOD COMPARISON
HOCKEYS - 215004 [D7]

APPENDIX B33

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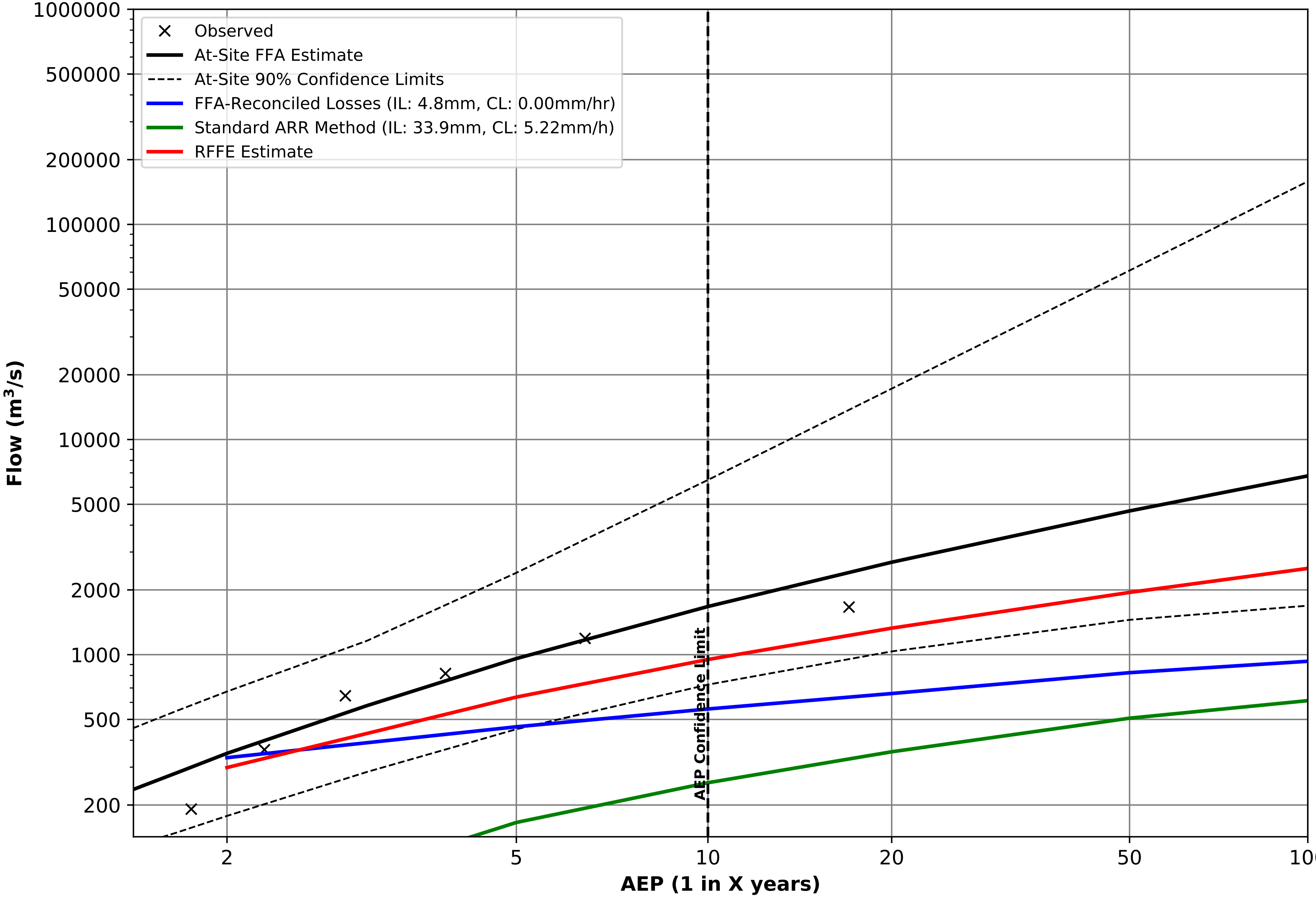

METHOD COMPARISON
NOWRA ROAD - 215009 [D8]

APPENDIX B34

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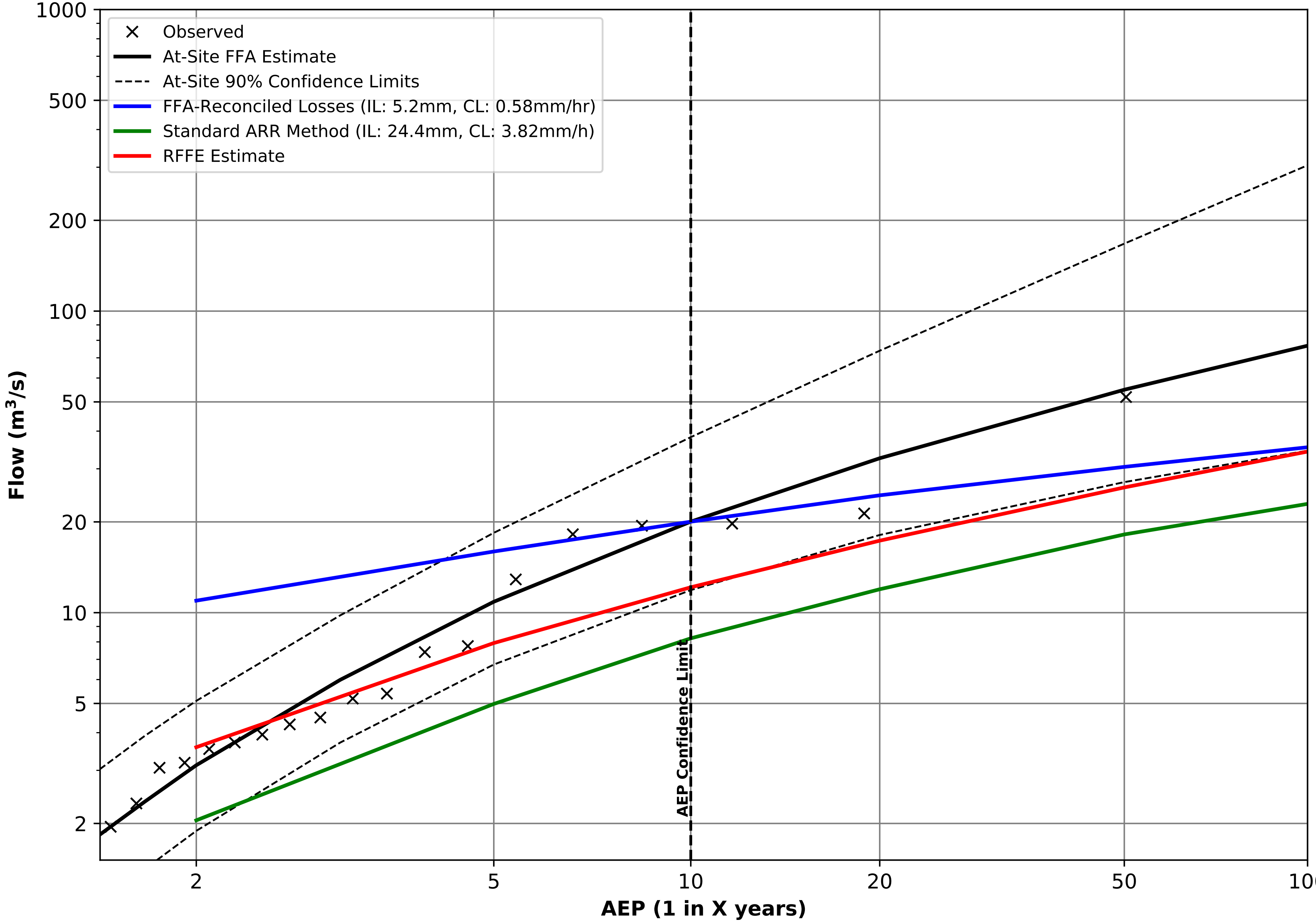
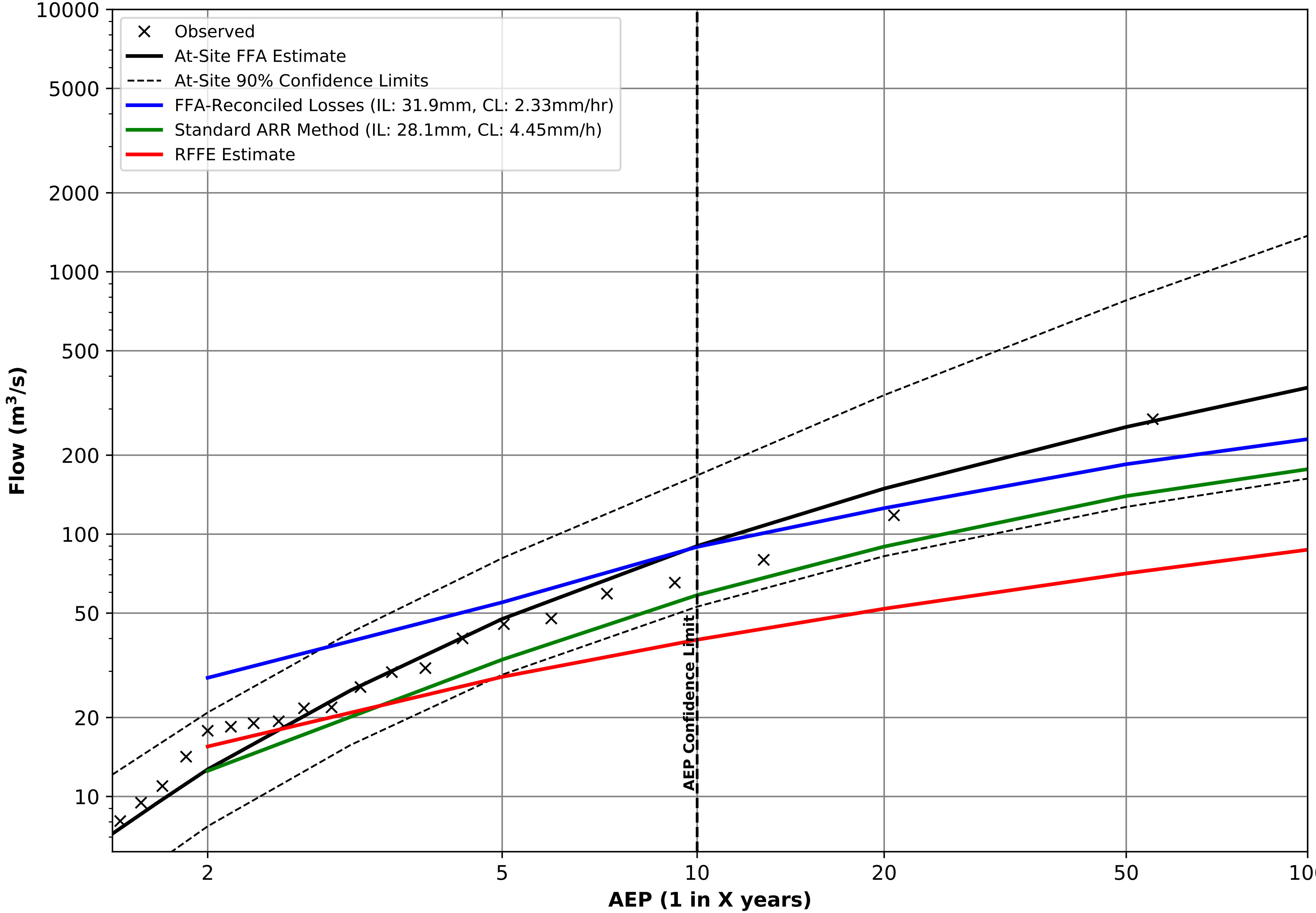


METHOD COMPARISON
WHITE HILL - 410160 [E1]

APPENDIX B35



METHOD COMPARISON
BOOK BOOK - 410156 [E2]

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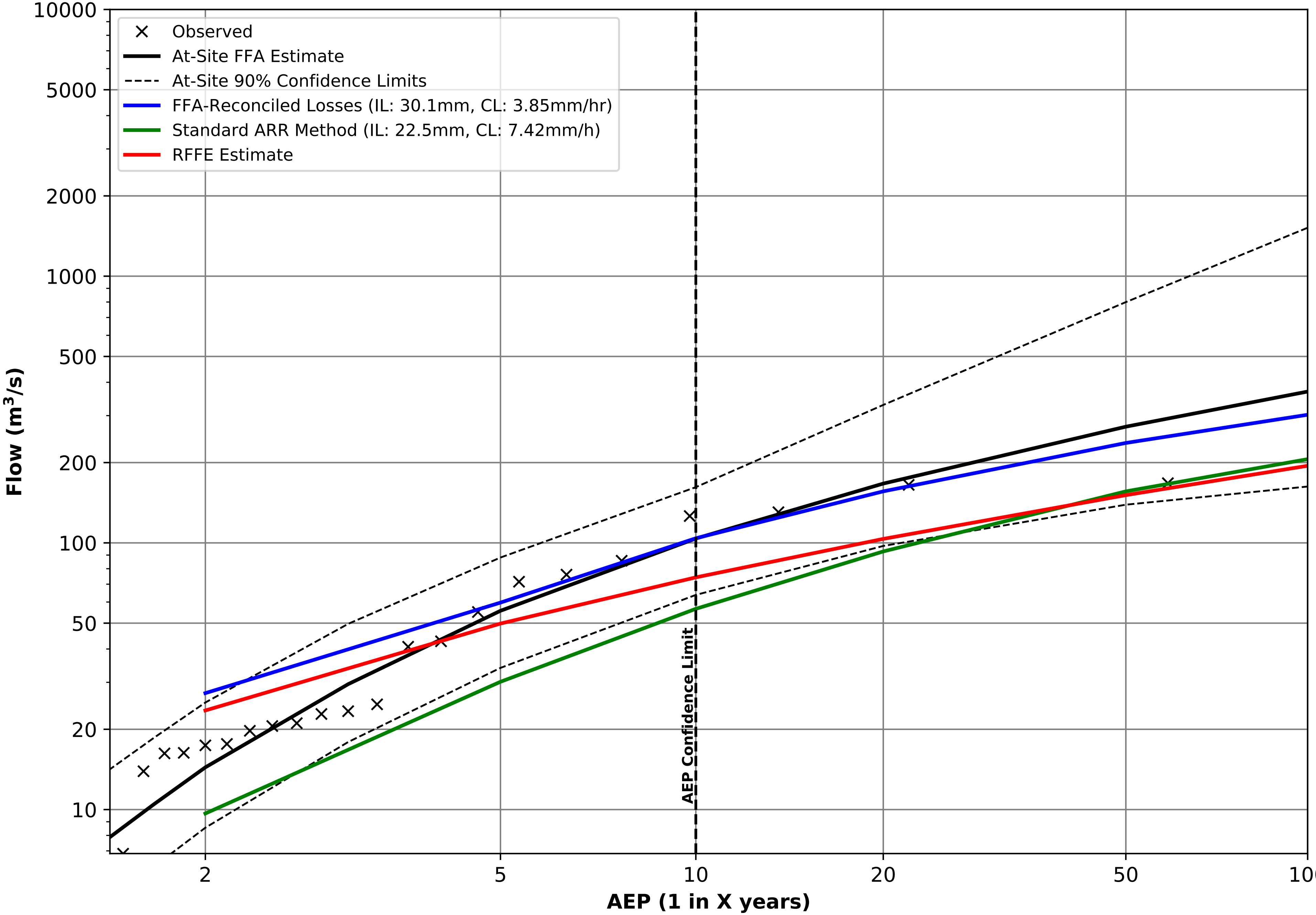

METHOD COMPARISON
MICHELAGO - 410141 [E3]

APPENDIX B37

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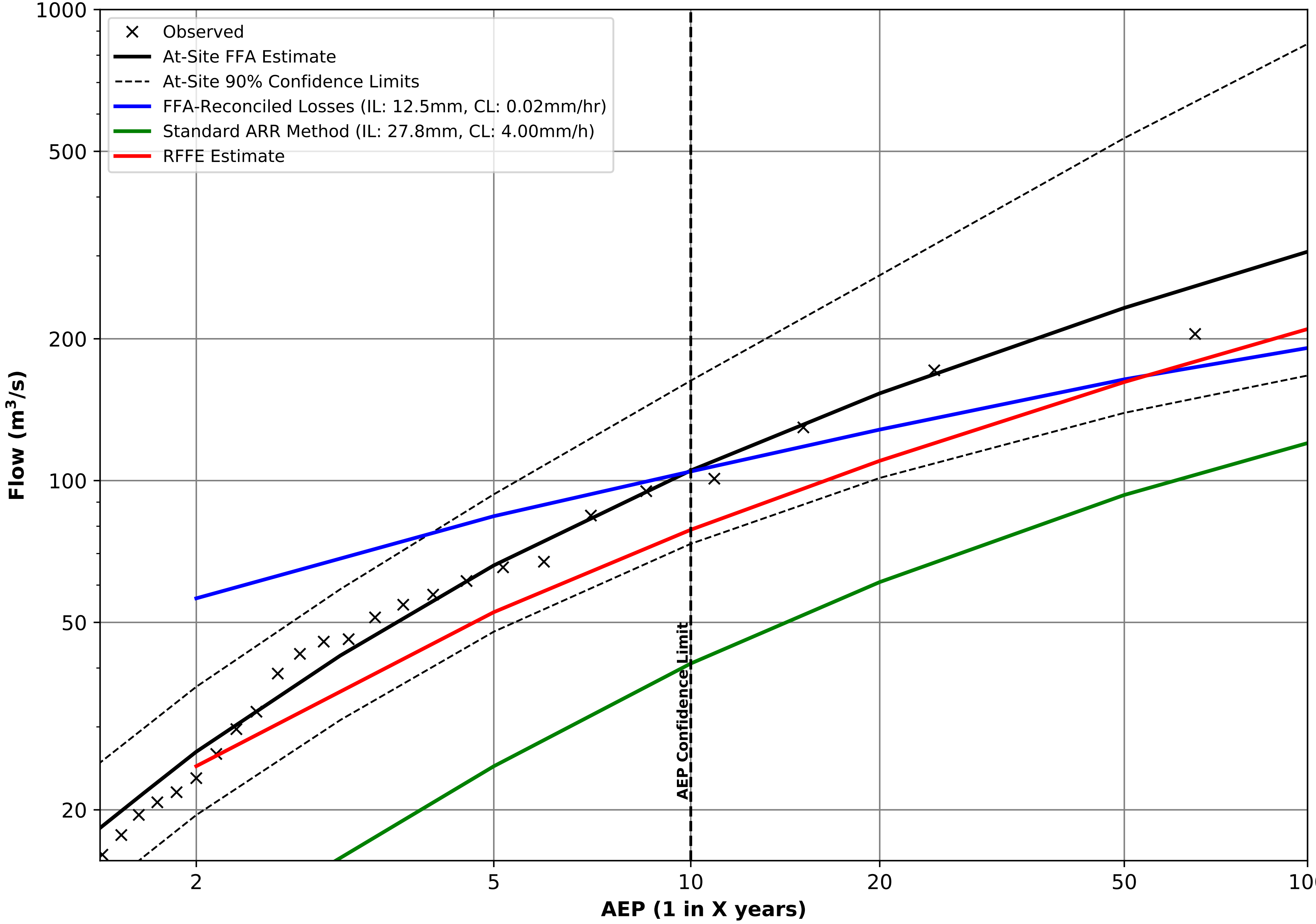

METHOD COMPARISON
BUTMAROO - 411003 [E4]

APPENDIX B38

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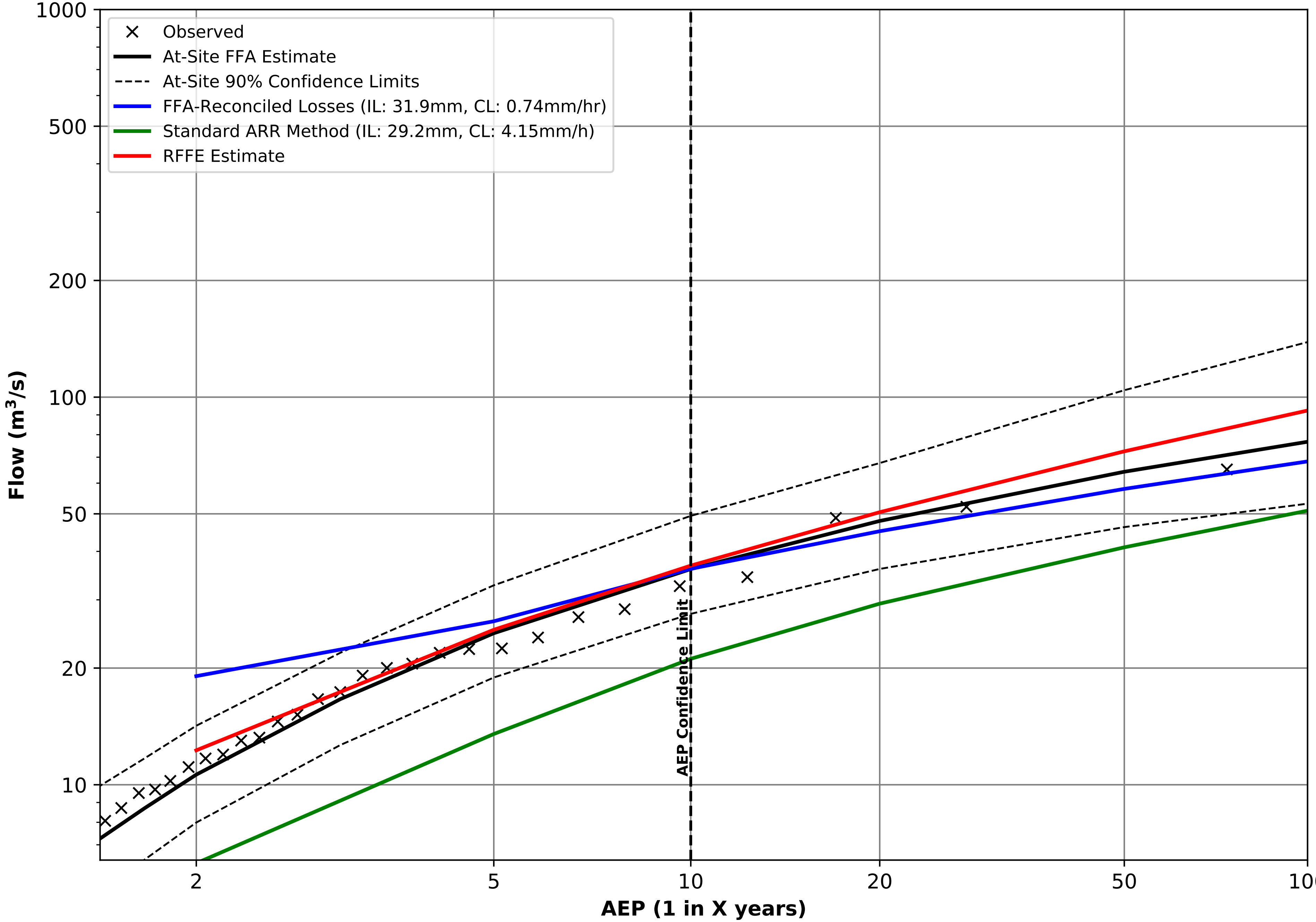

METHOD COMPARISON
WYANGLE - 410114 [E5]

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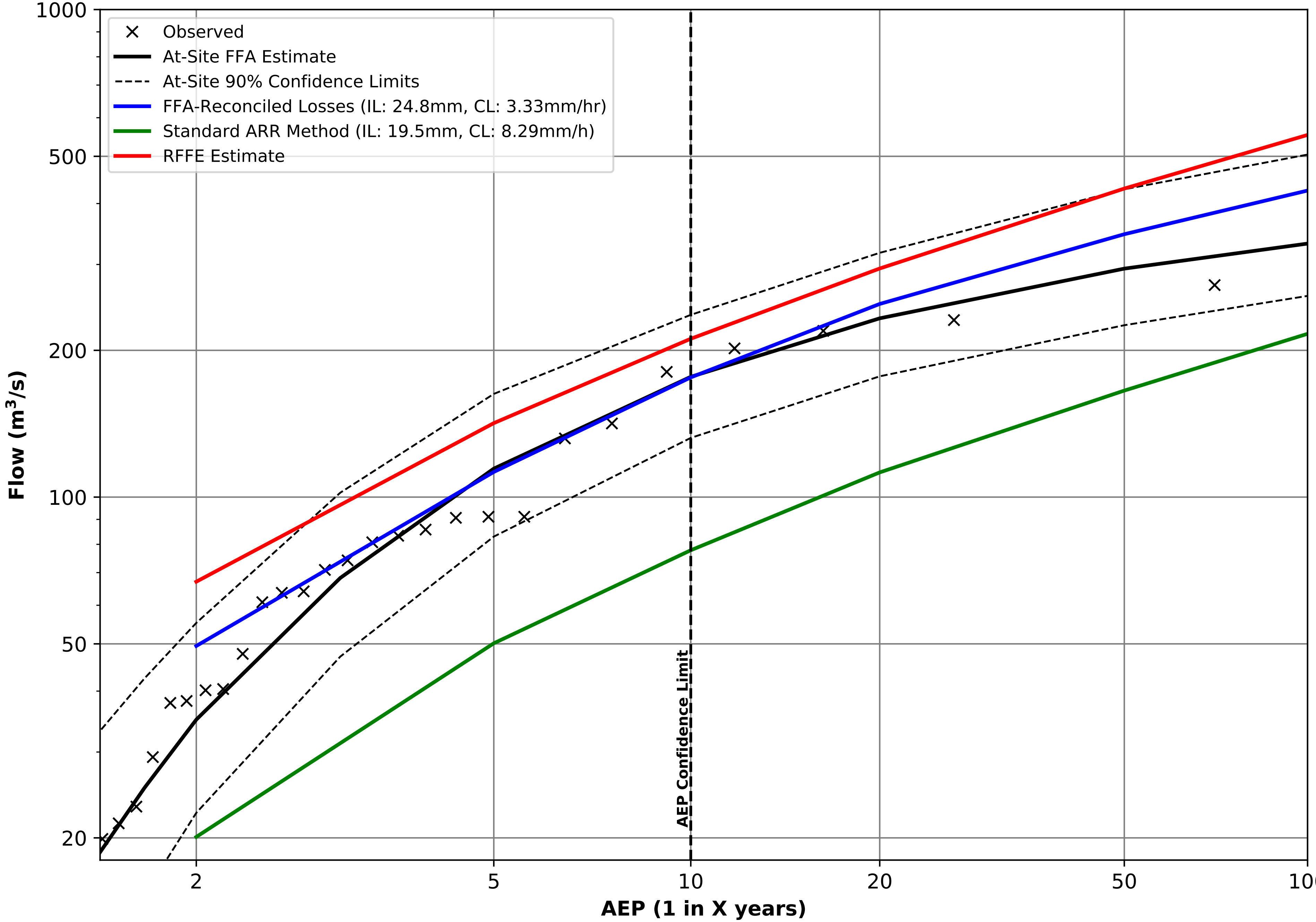

METHOD COMPARISON
JERANGLE RD - 410076 [E6]

APPENDIX B40

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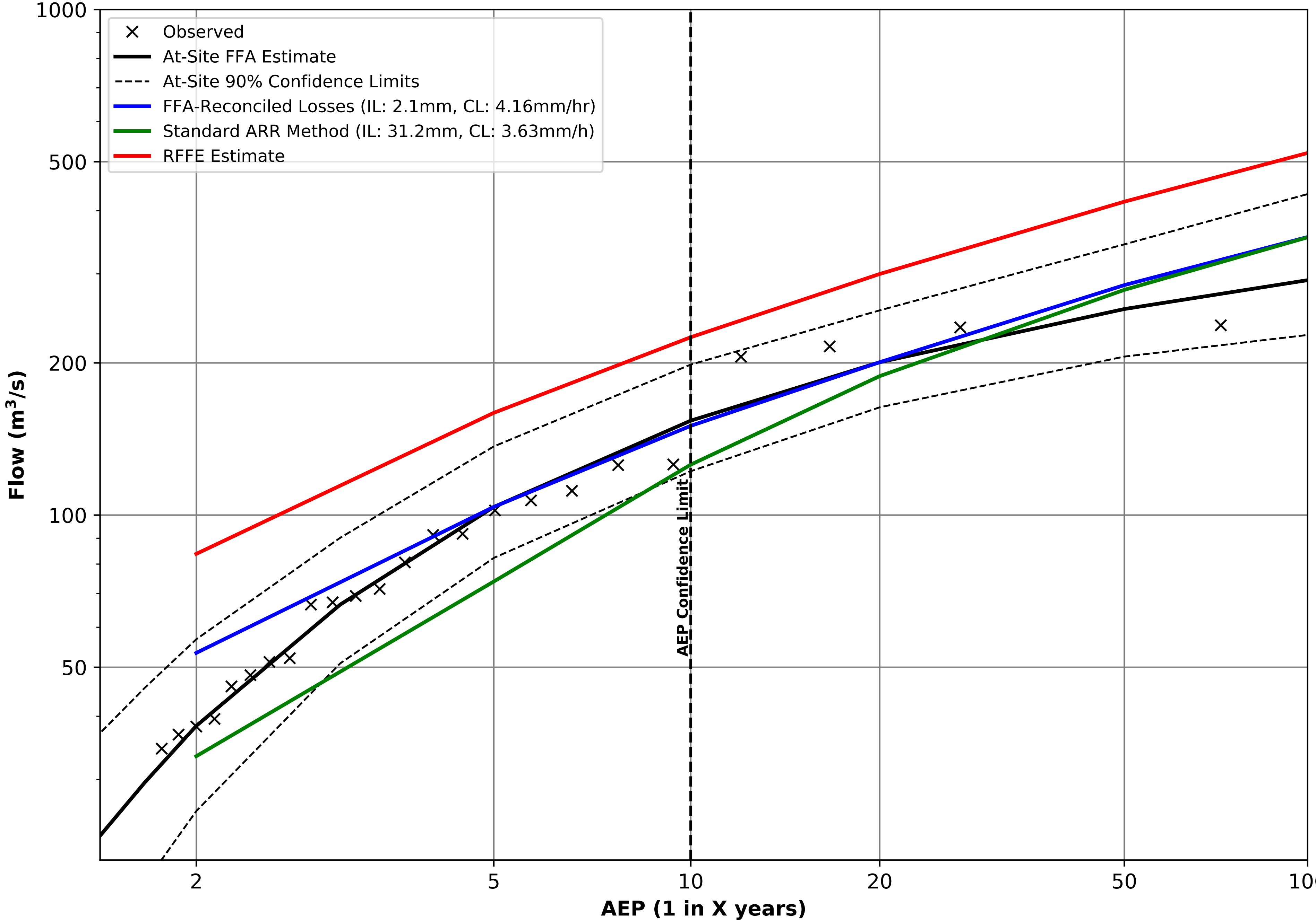
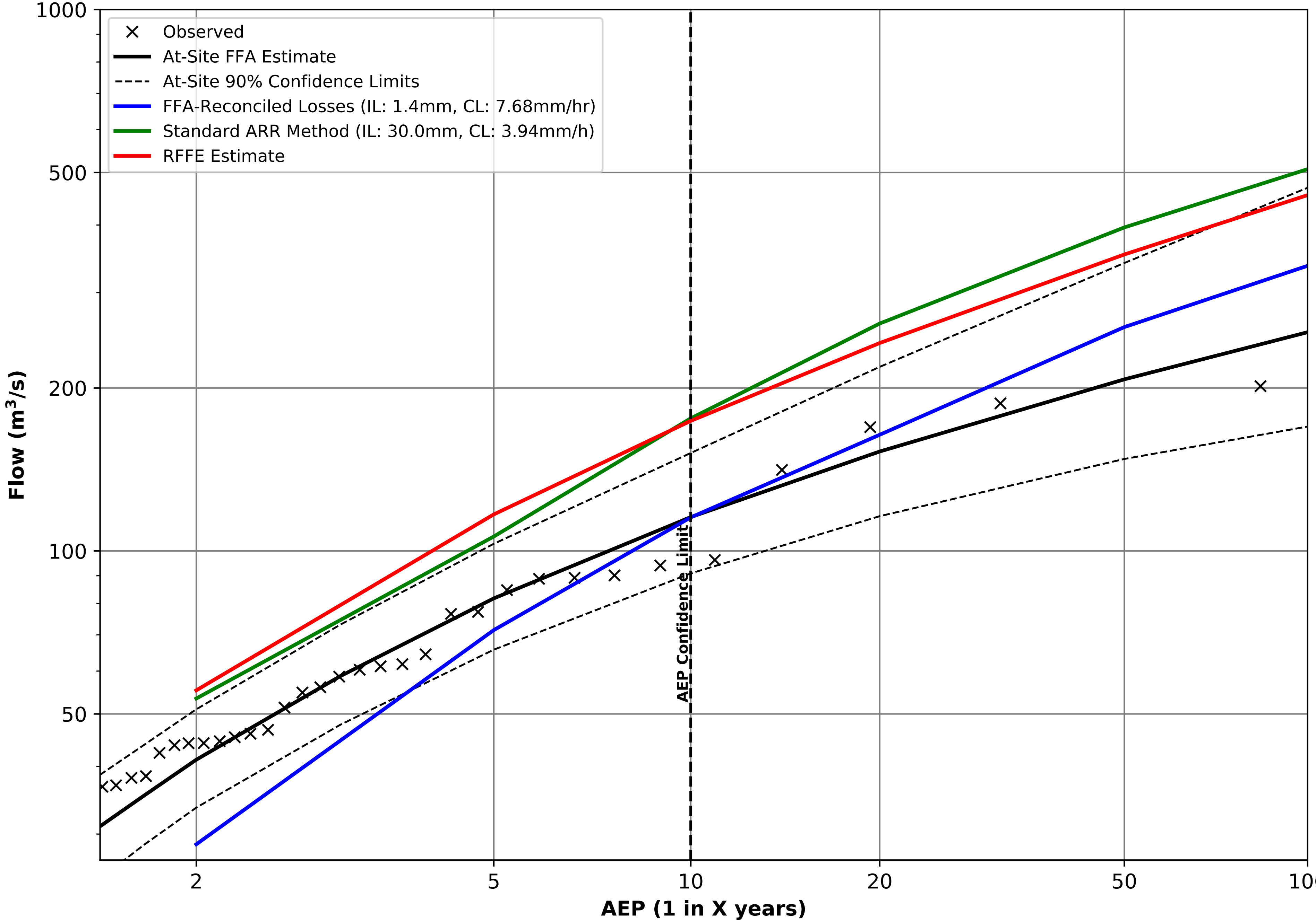


METHOD COMPARISON
MOUNTAIN CK - 410107 [E7]

APPENDIX B41



METHOD COMPARISON
DARBALARA - 410038 [E8]

APPENDIX B42

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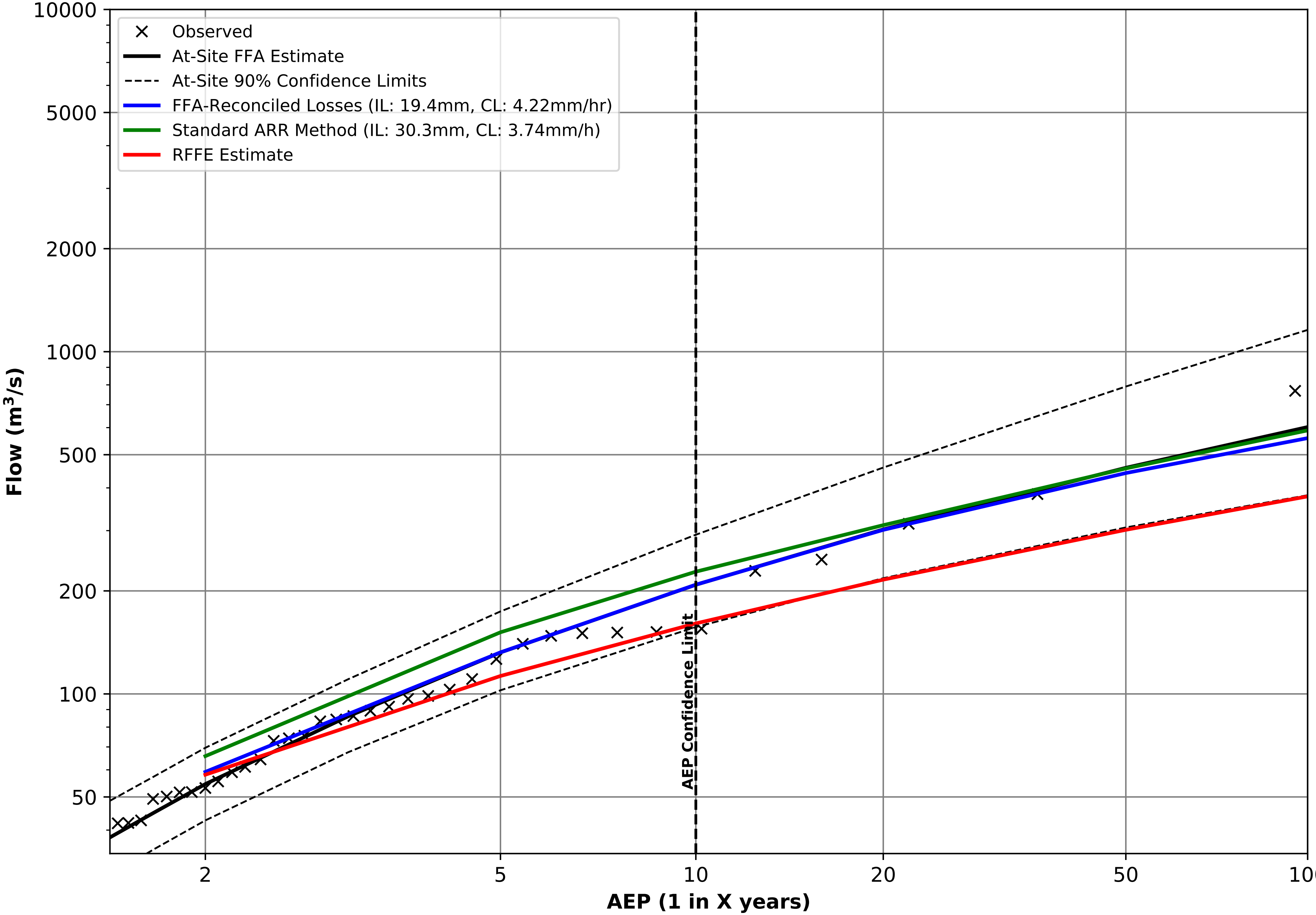

METHOD COMPARISON

BRINDABELLA (NO.2&NO.3-CAB - 410088 [E9]

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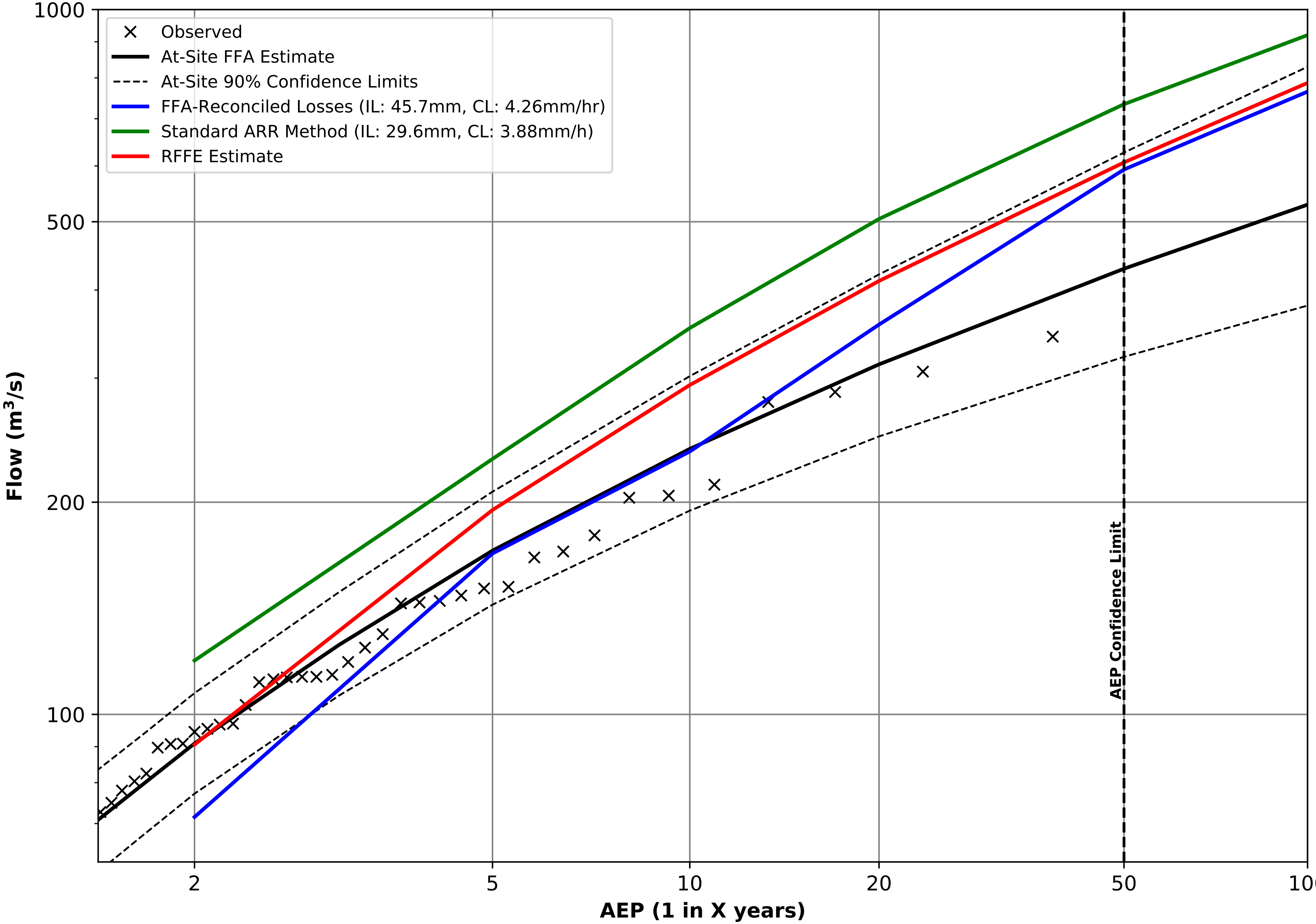
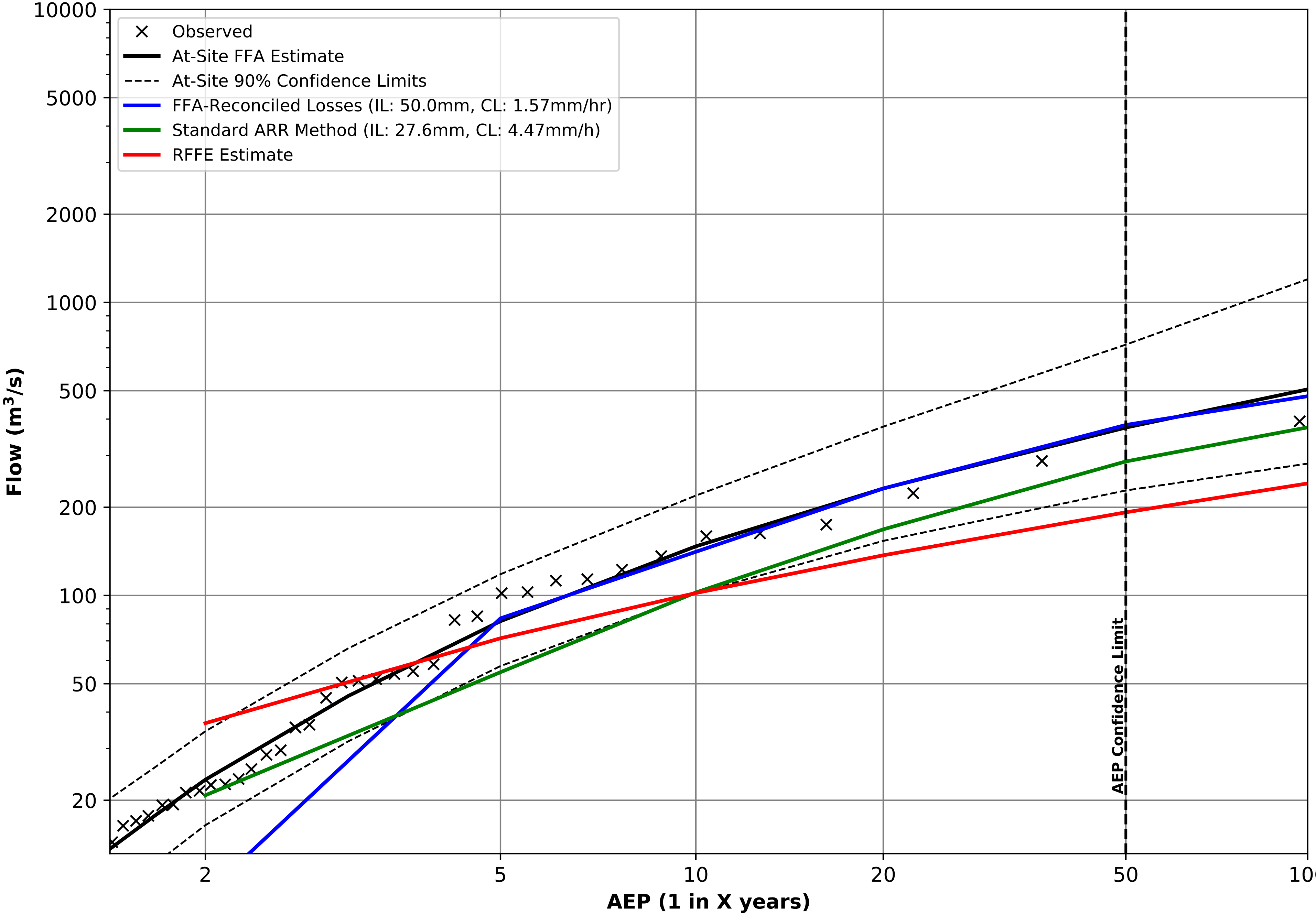


METHOD COMPARISON
LACMALAC - 410057 [E10]



METHOD COMPARISON
LADYSMITH - 410048 [E11]

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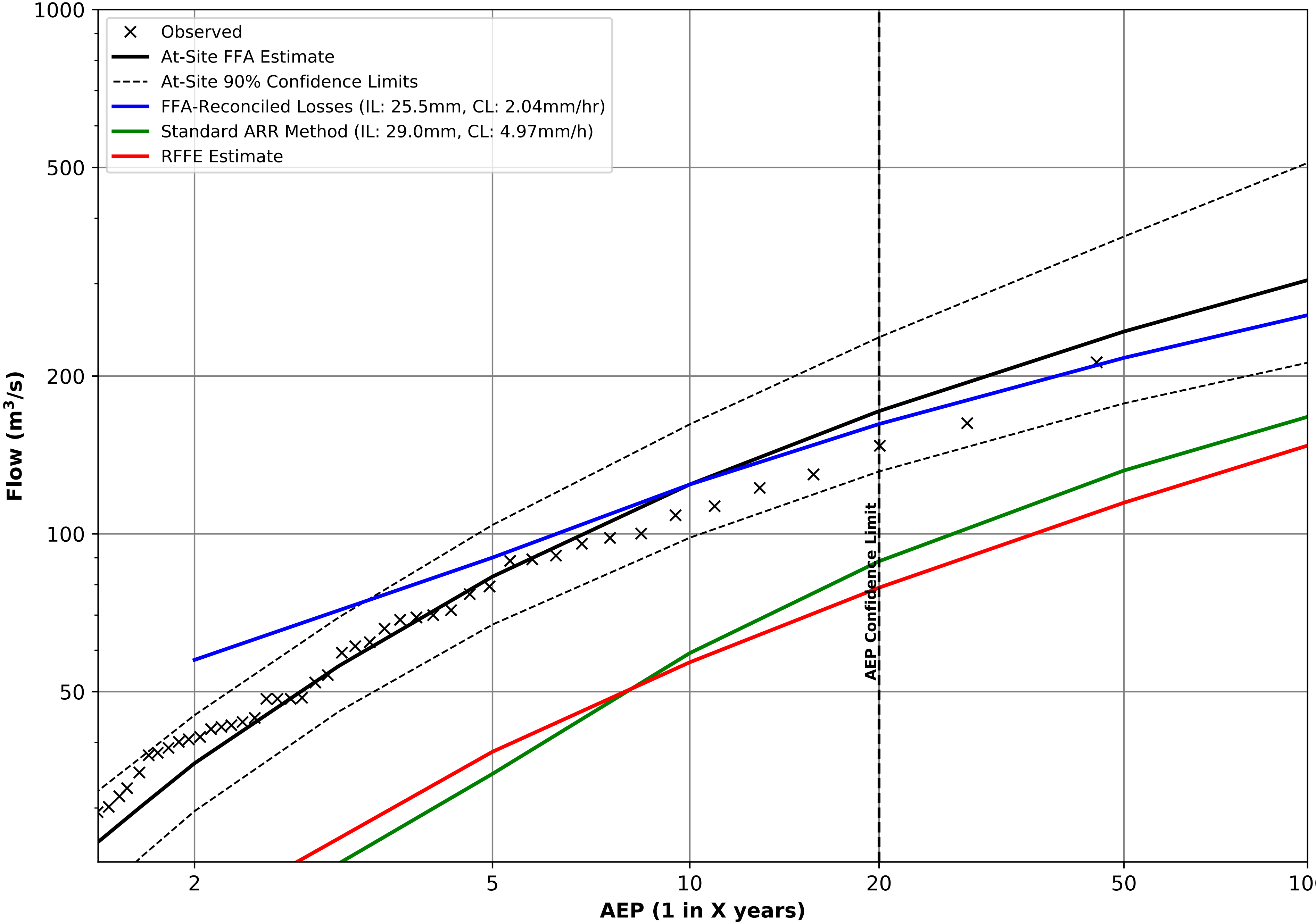

METHOD COMPARISON
BATLOW RD - 410061 [E12]

APPENDIX B46

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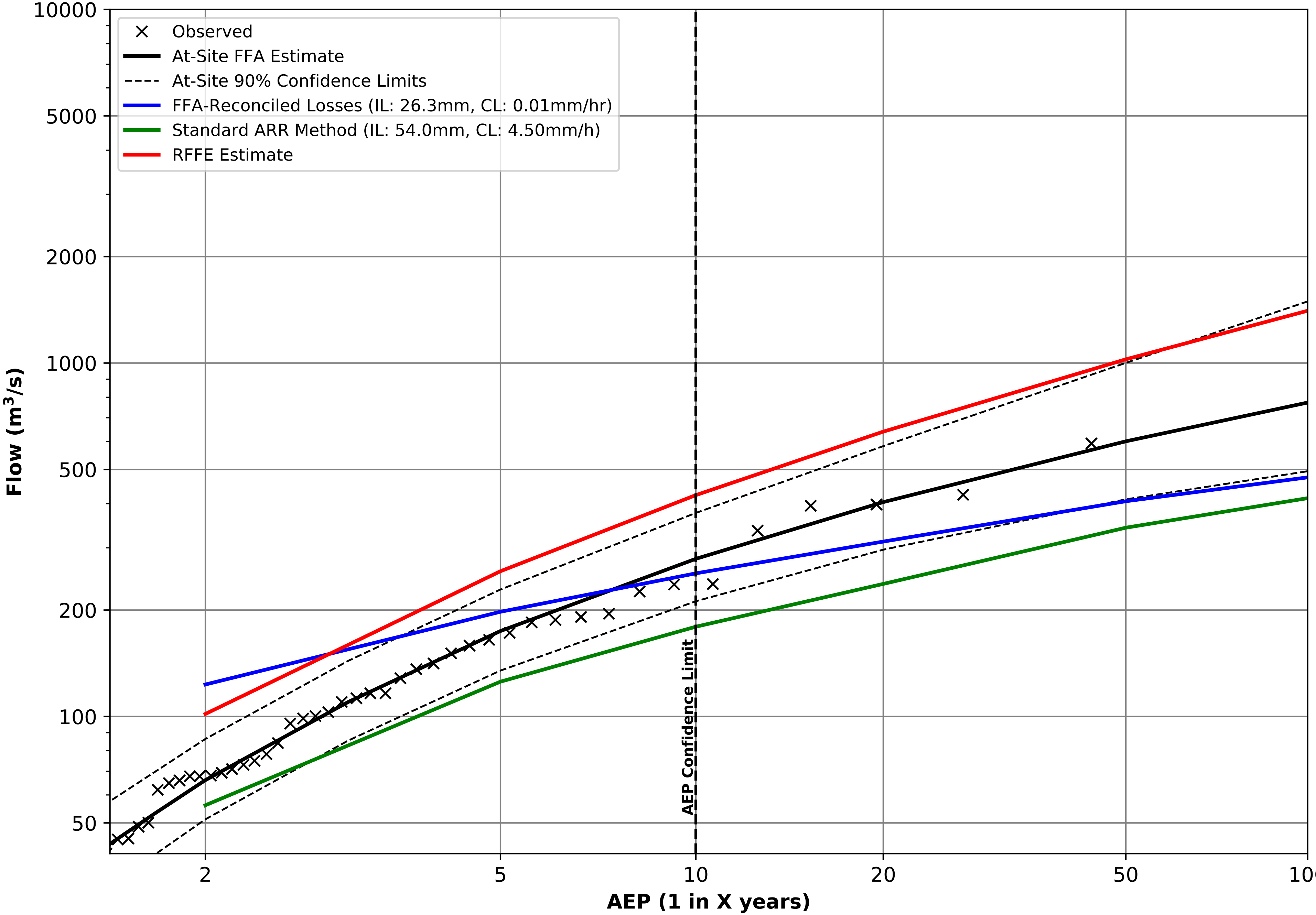

METHOD COMPARISON
ALBION PARK - 214003 [F1]

APPENDIX B47

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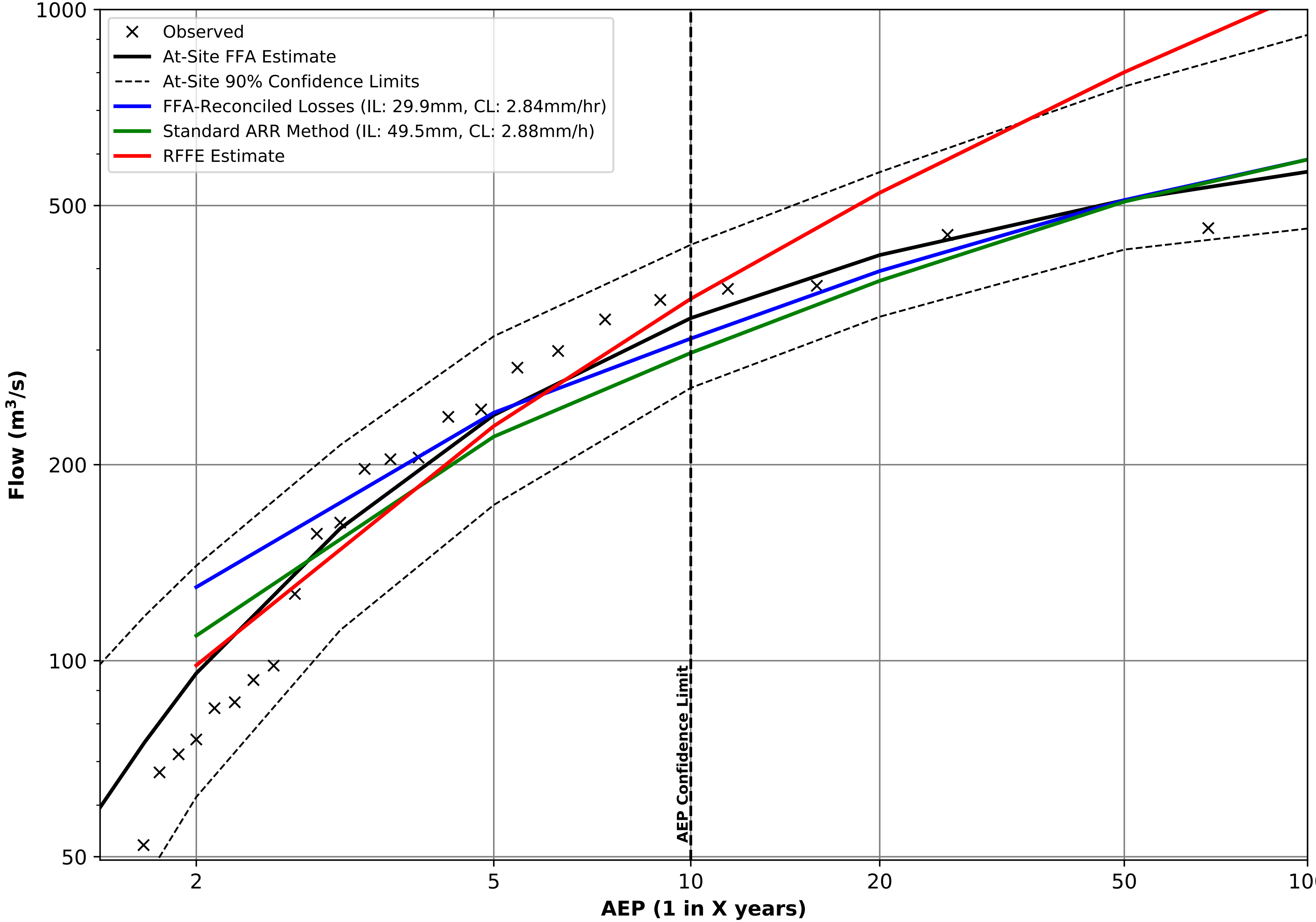
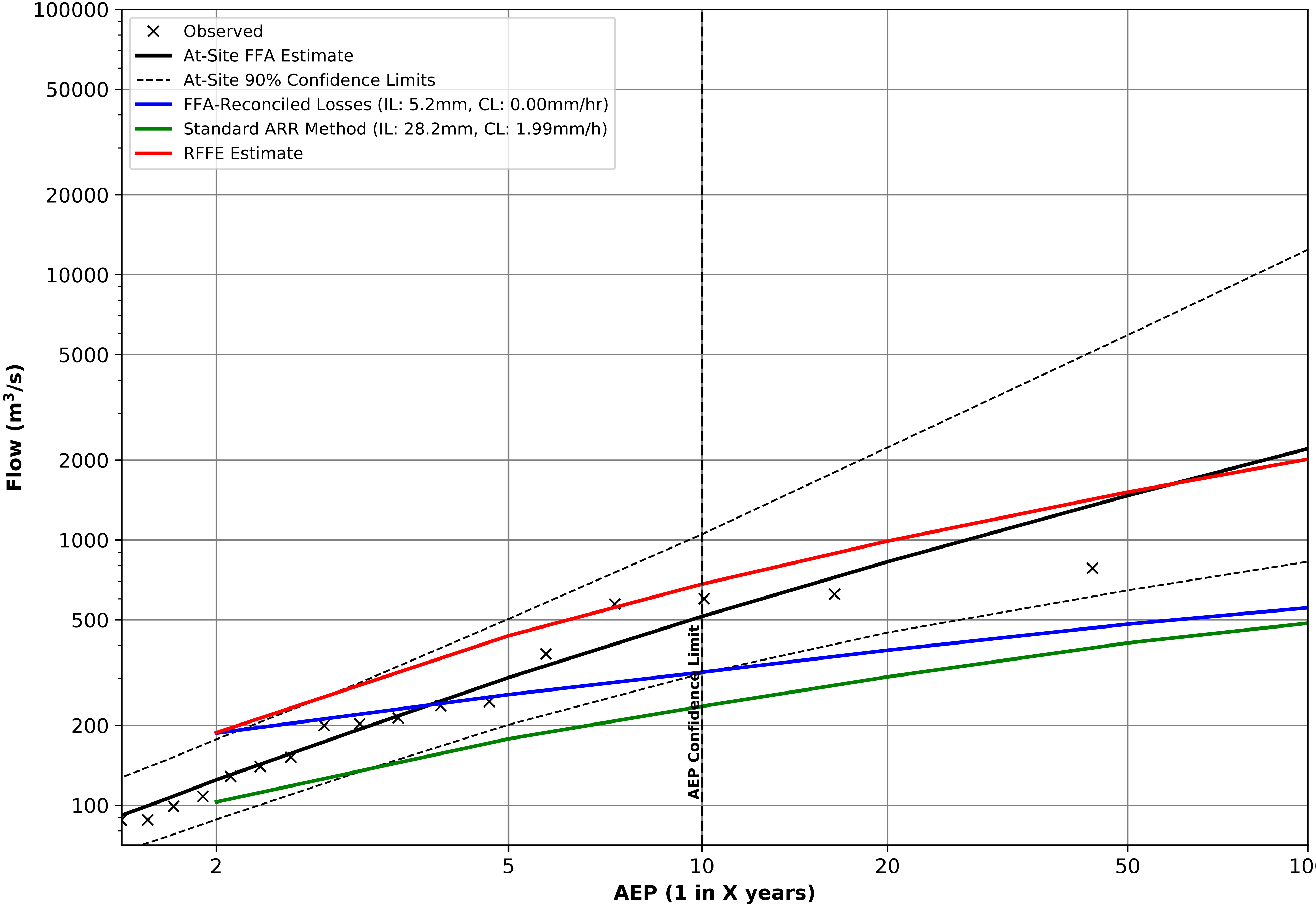


METHOD COMPARISON
WEDDERBURN - 213200 [F2]

APPENDIX B48



METHOD COMPARISON
PARRAMATTA HOSPITAL - 213004 [F3]

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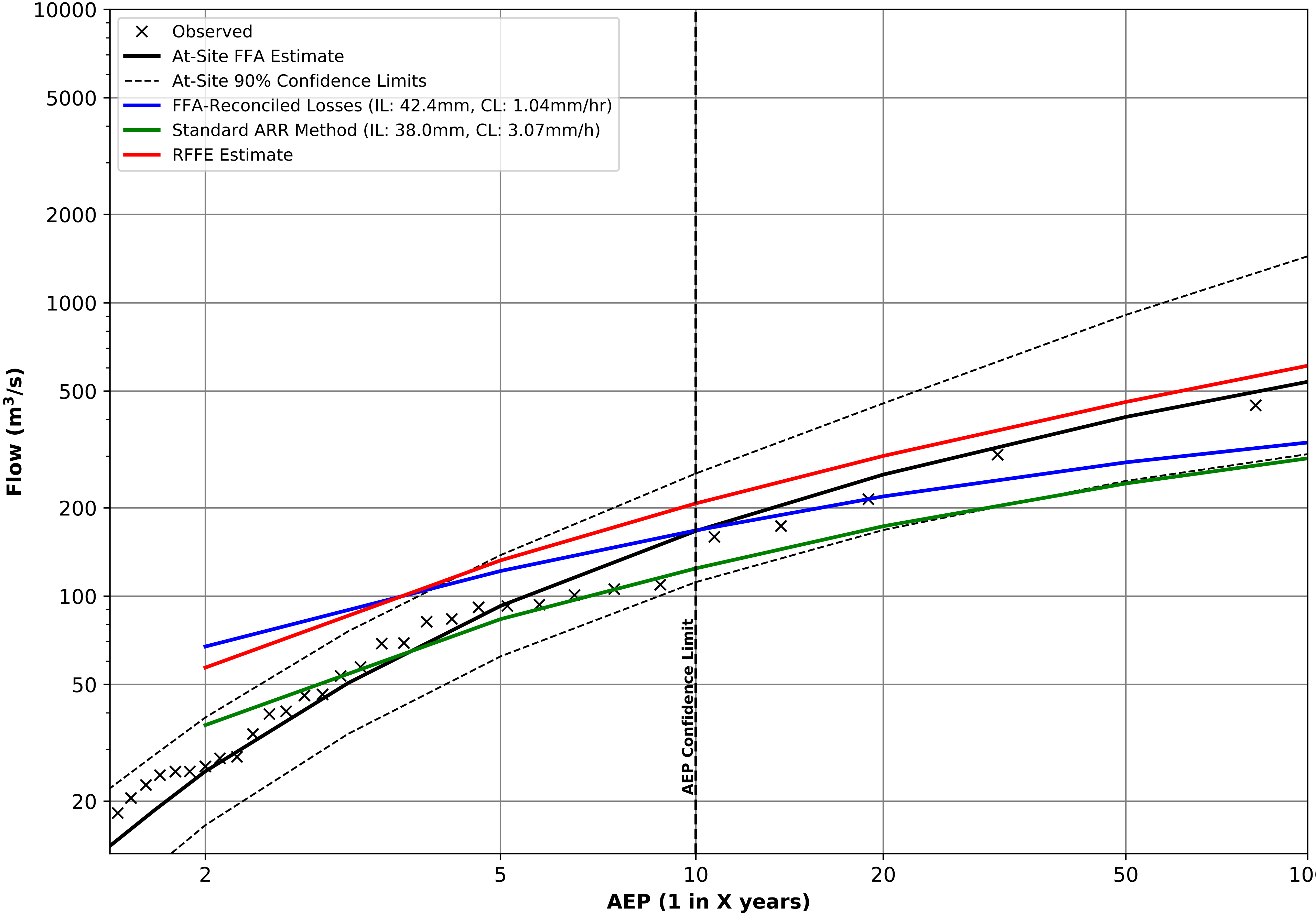

METHOD COMPARISON
MULGOA RD - 212320 [F4]

APPENDIX B50

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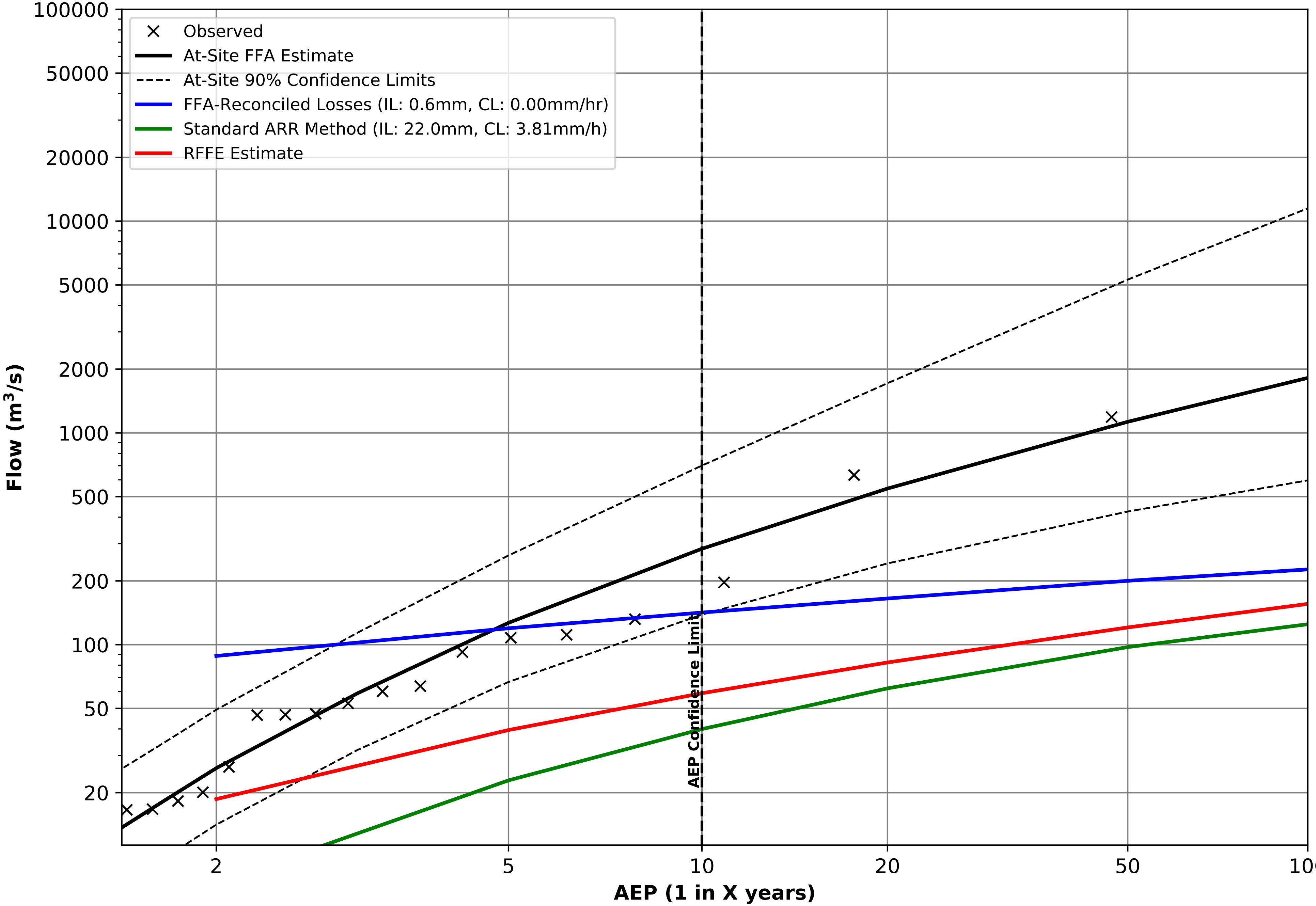
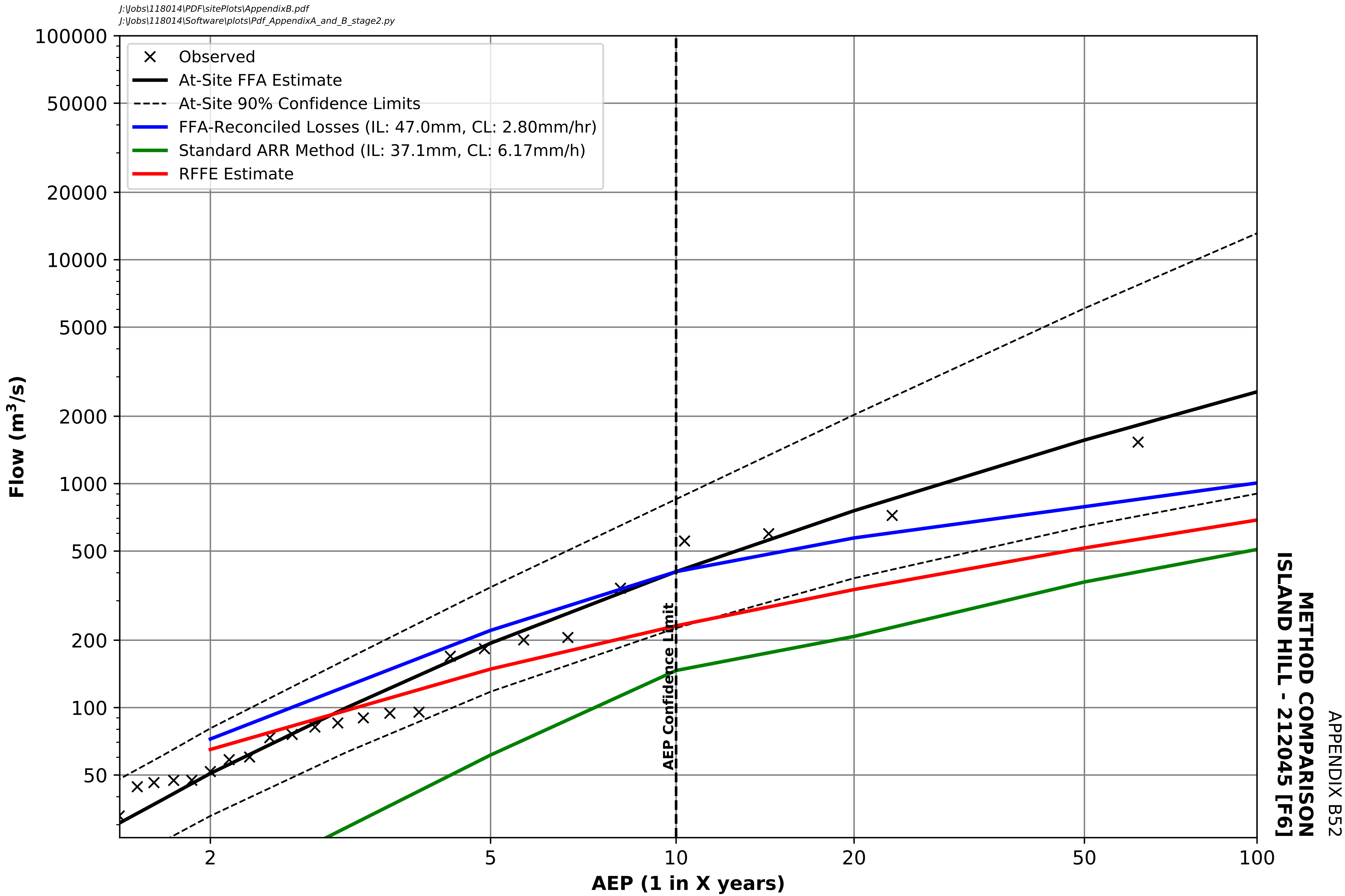


METHOD COMPARISON
POMEROY - 212040 [F5]

APPENDIX B51



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Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 47.0mm, CL: 2.80mm/hr)
Standard ARR Method (IL: 37.1mm, CL: 6.17mm/h)
RFFE Estimate
AEP Confidence Limit
Flow (m³/s)
100000
50000
20000
10000
5000
2000
1000
500
200
100
50
2
5
10
20
50
100
AEP (1 in X years)
METHOD COMPARISON
ISLAND HILL - 212045 [F6]
APPENDIX B52

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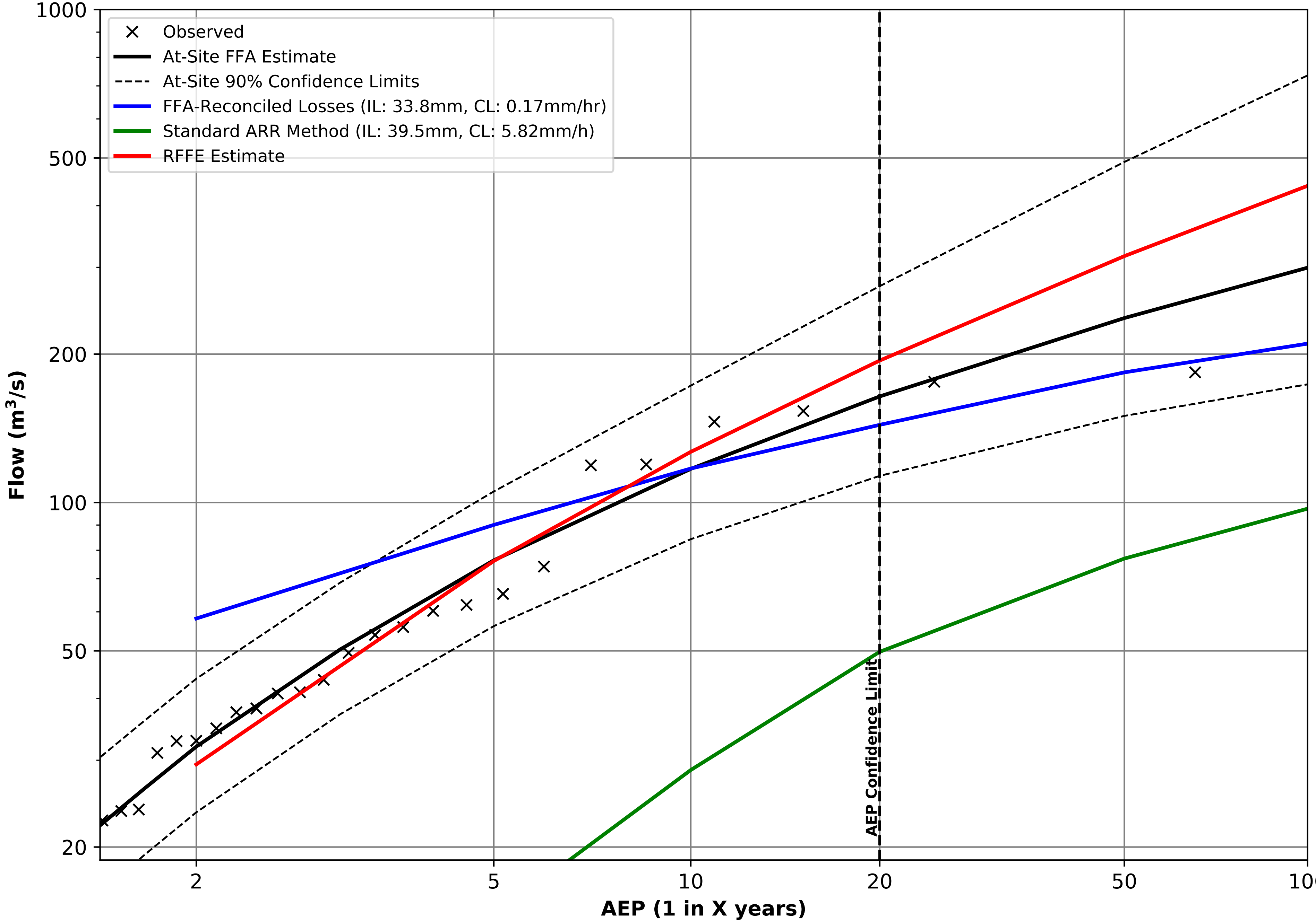

METHOD COMPARISON
MOUNT WALKER - 212042 [F7]

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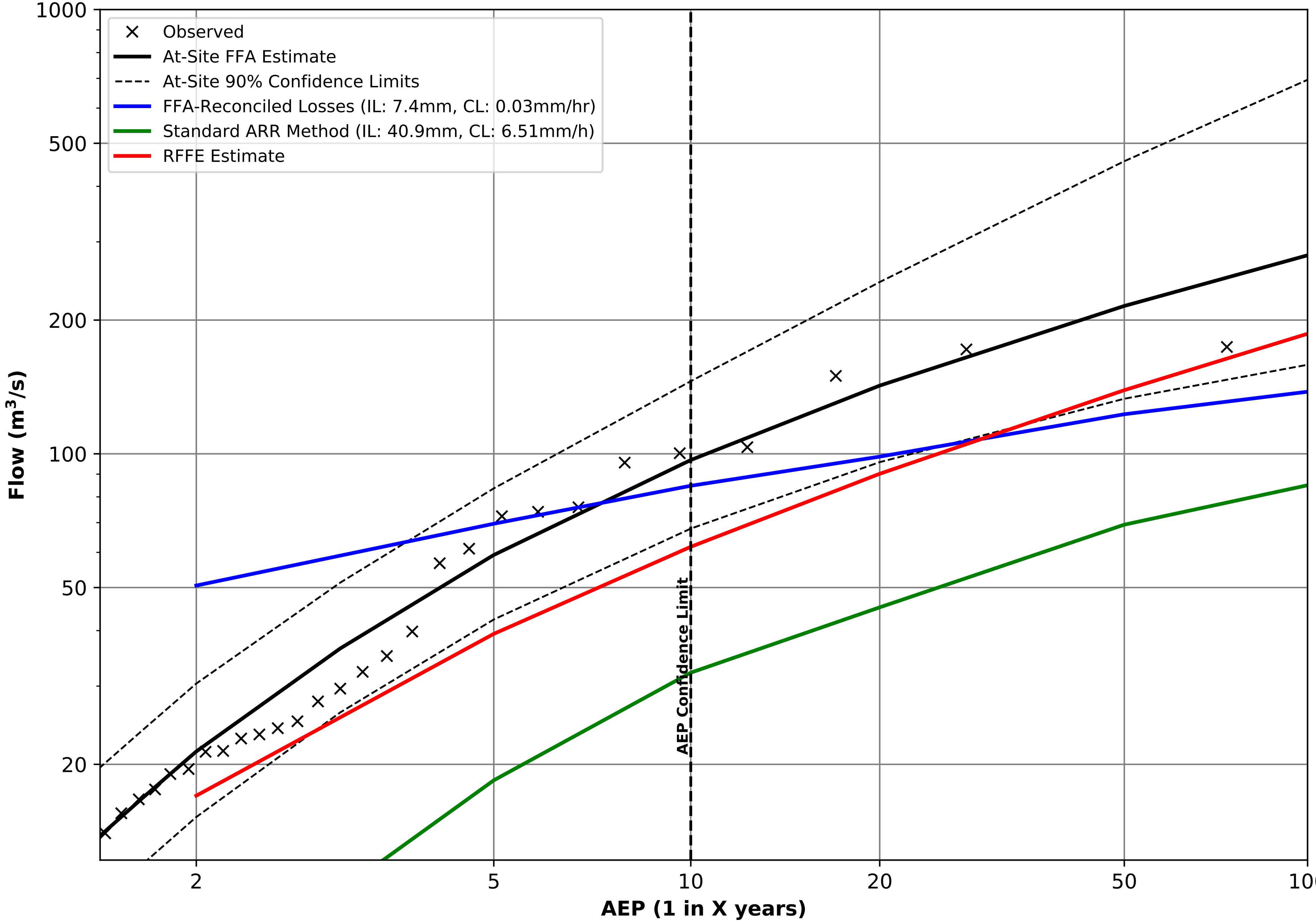
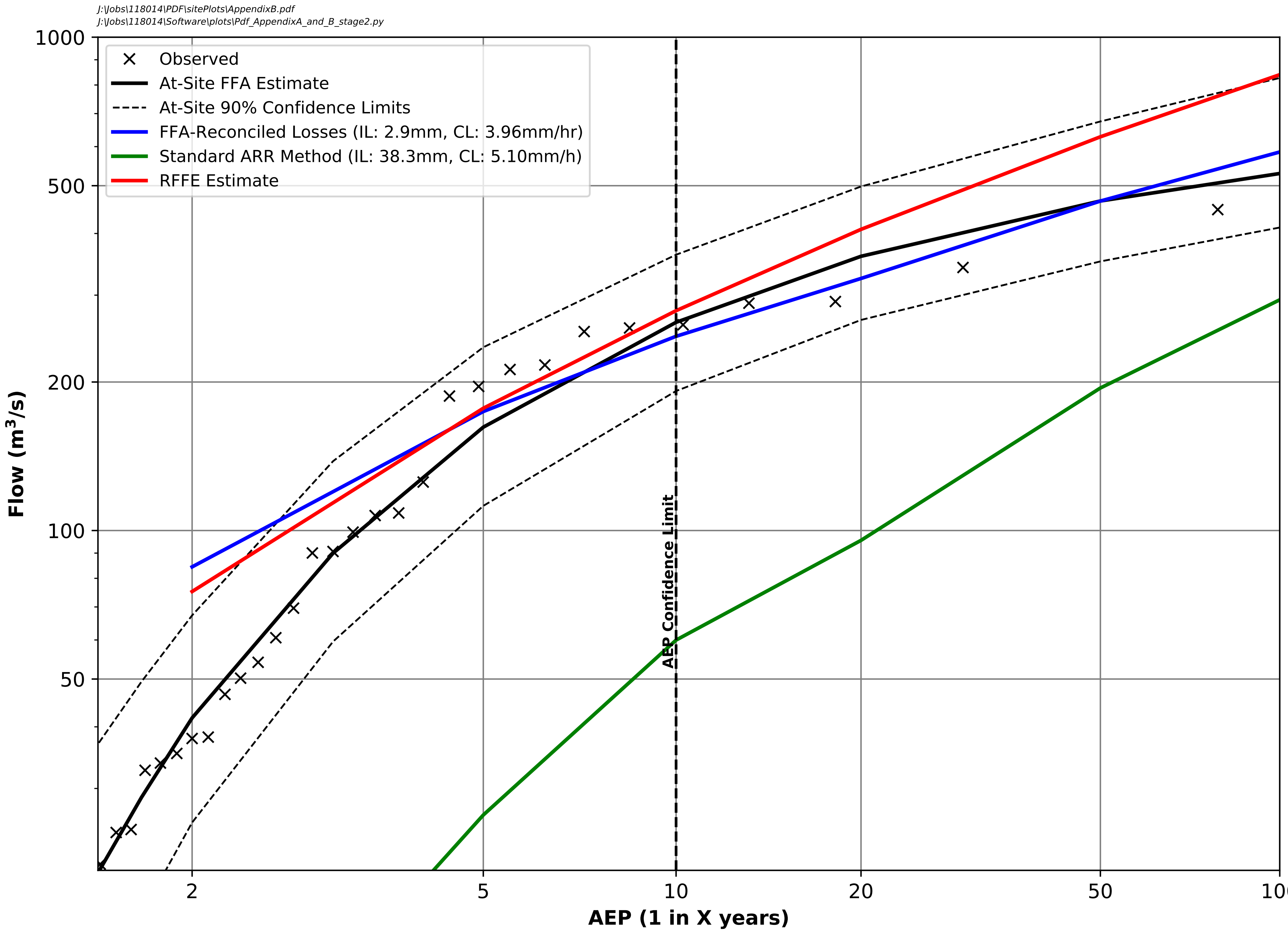


METHOD COMPARISON
NARROW NECK - 212013 [F8]



METHOD COMPARISON
GLEN DAVIS - 212018 [F9]

APPENDIX B55

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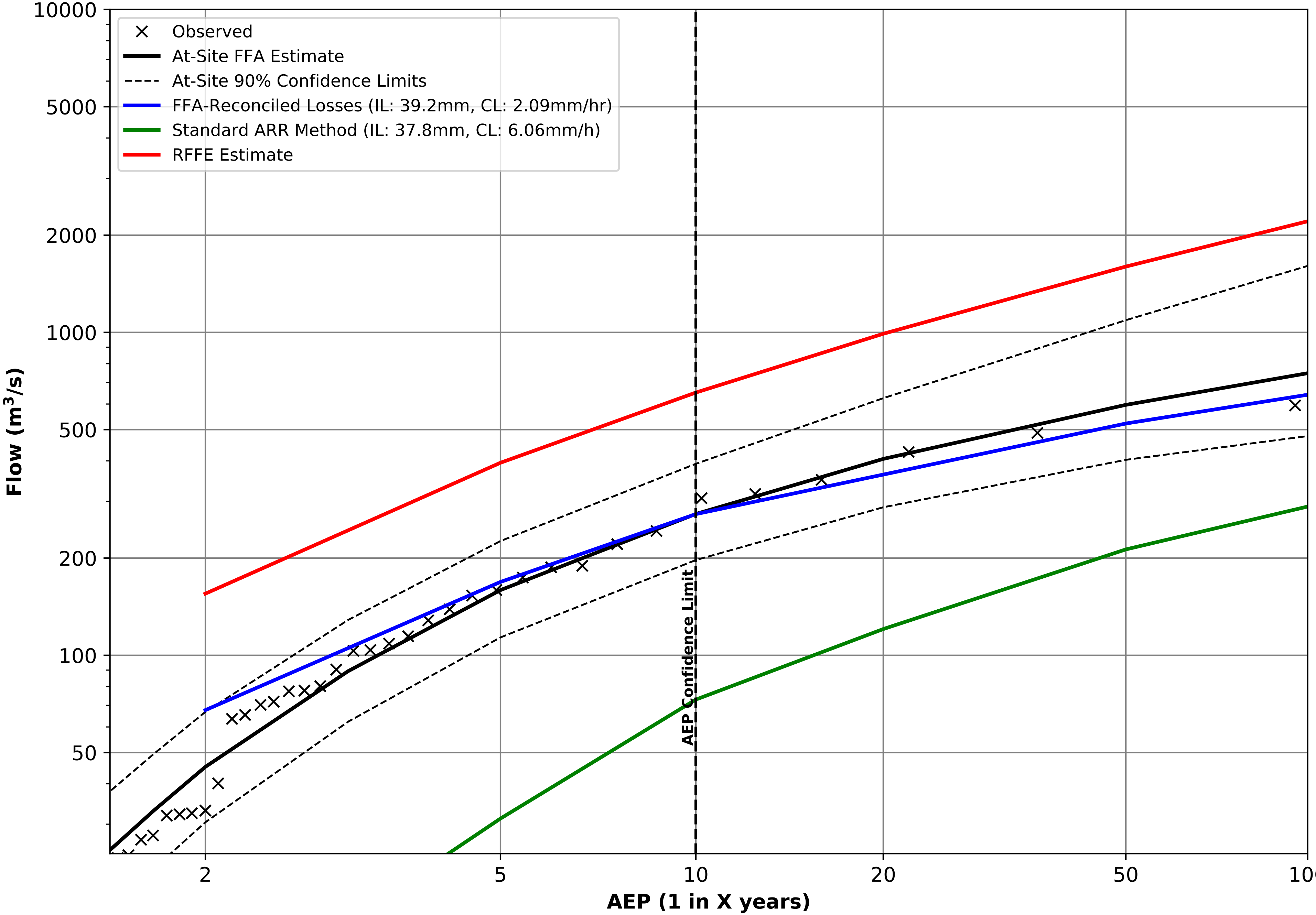
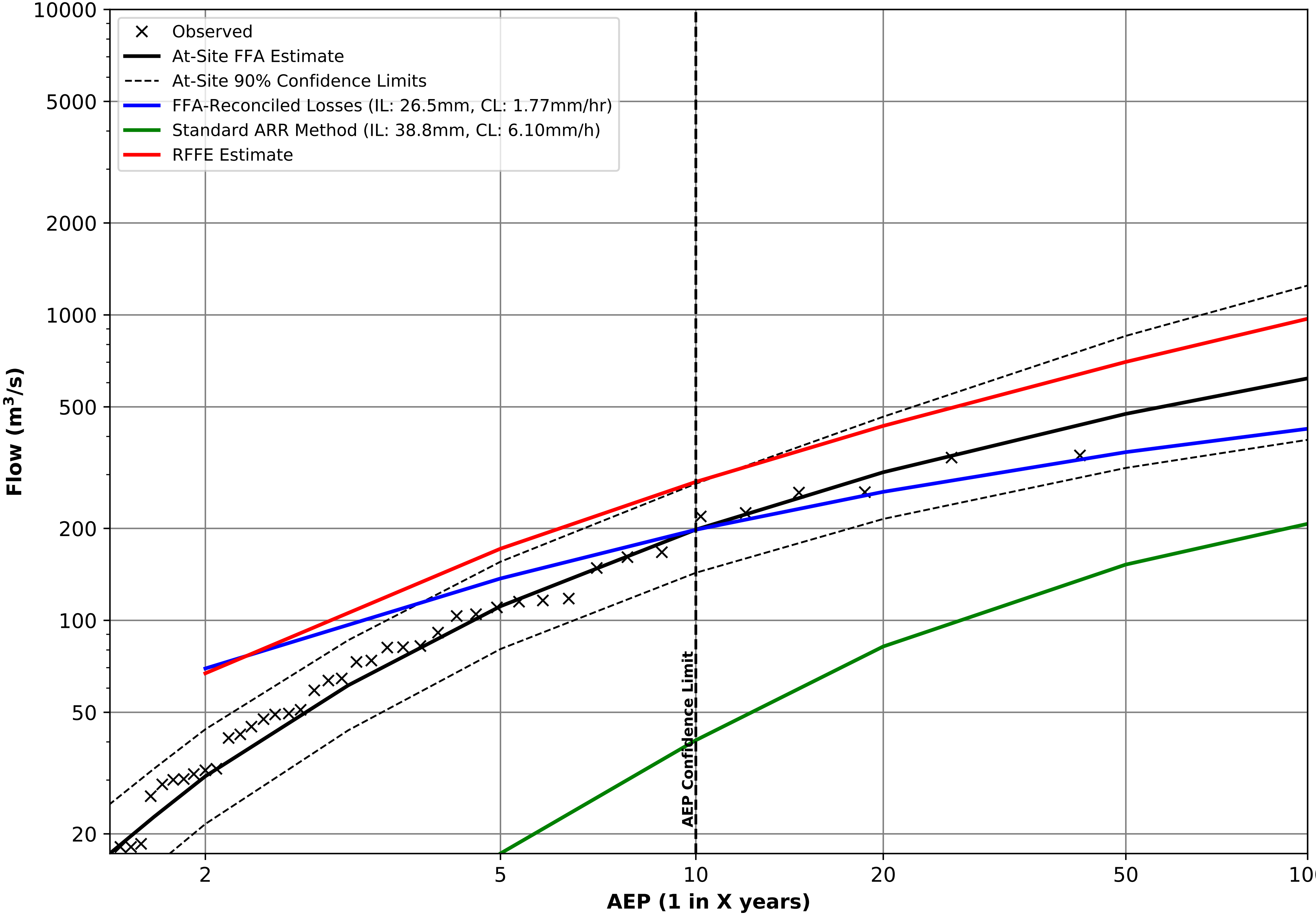


METHOD COMPARISON
LITHGOW - 212011 [F10]

APPENDIX B56



METHOD COMPARISON
BATHURST RD - 212008 [F11]

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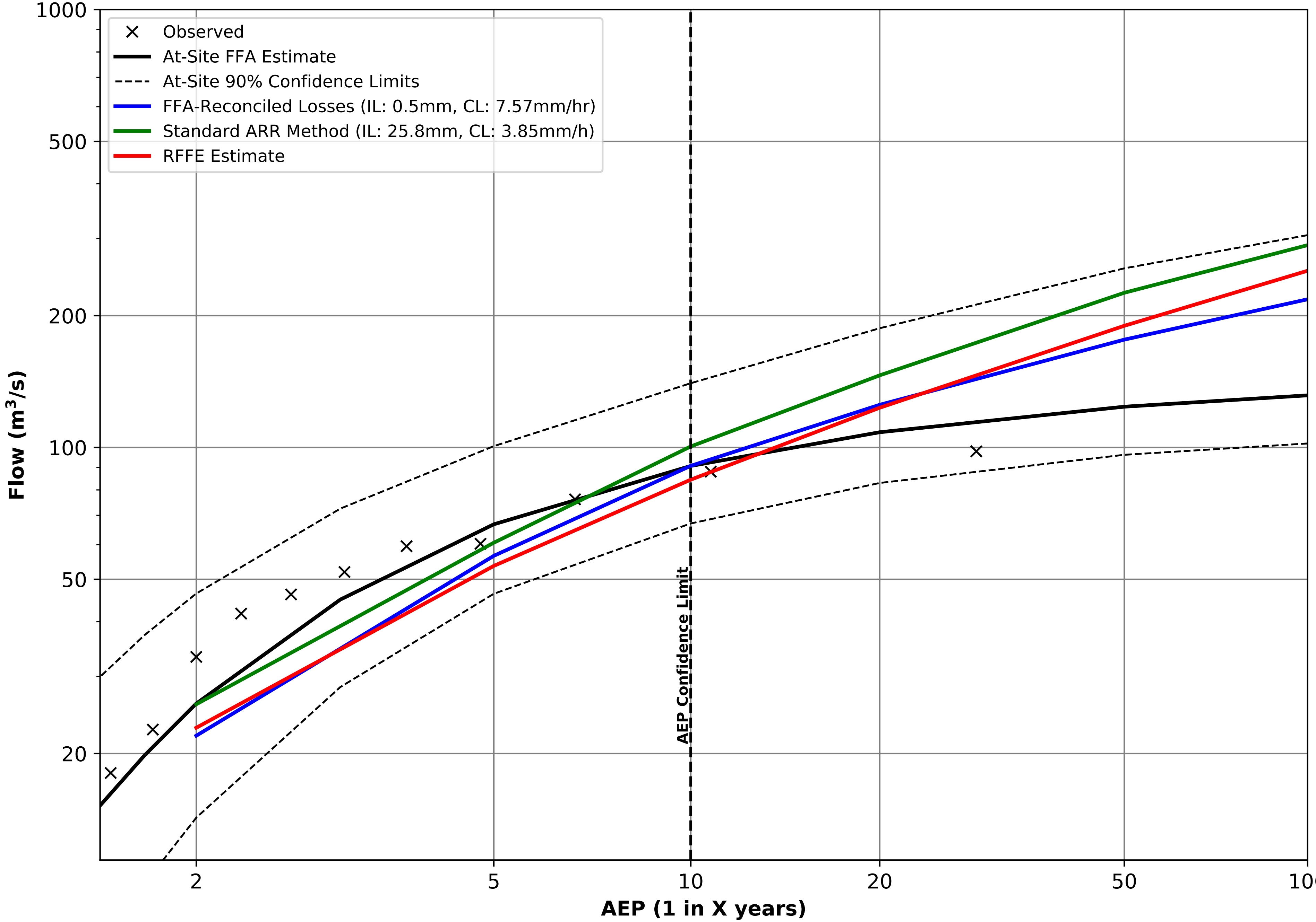

METHOD COMPARISON
CUDAL NO.2 - 412090 [G1]

APPENDIX B58

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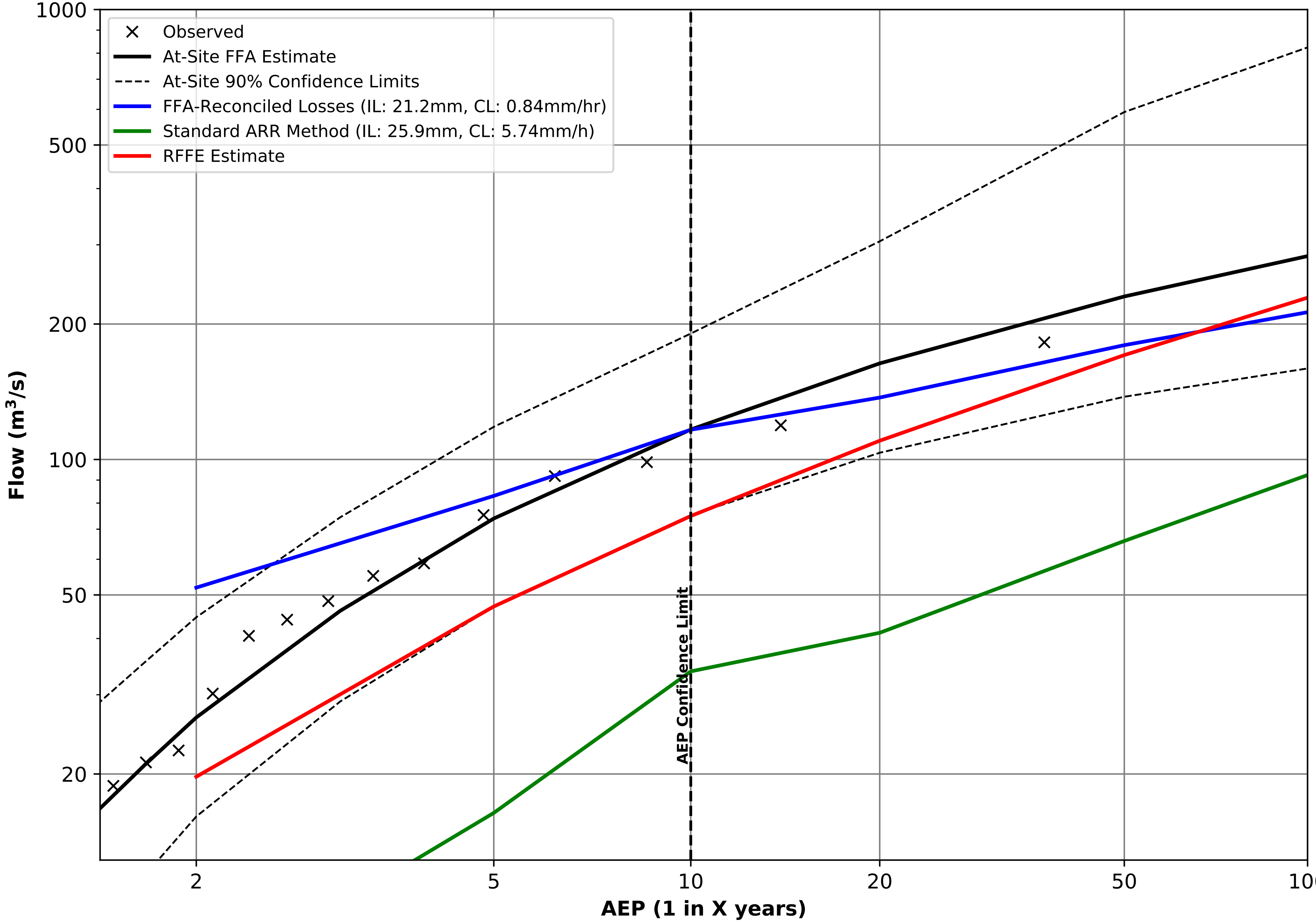
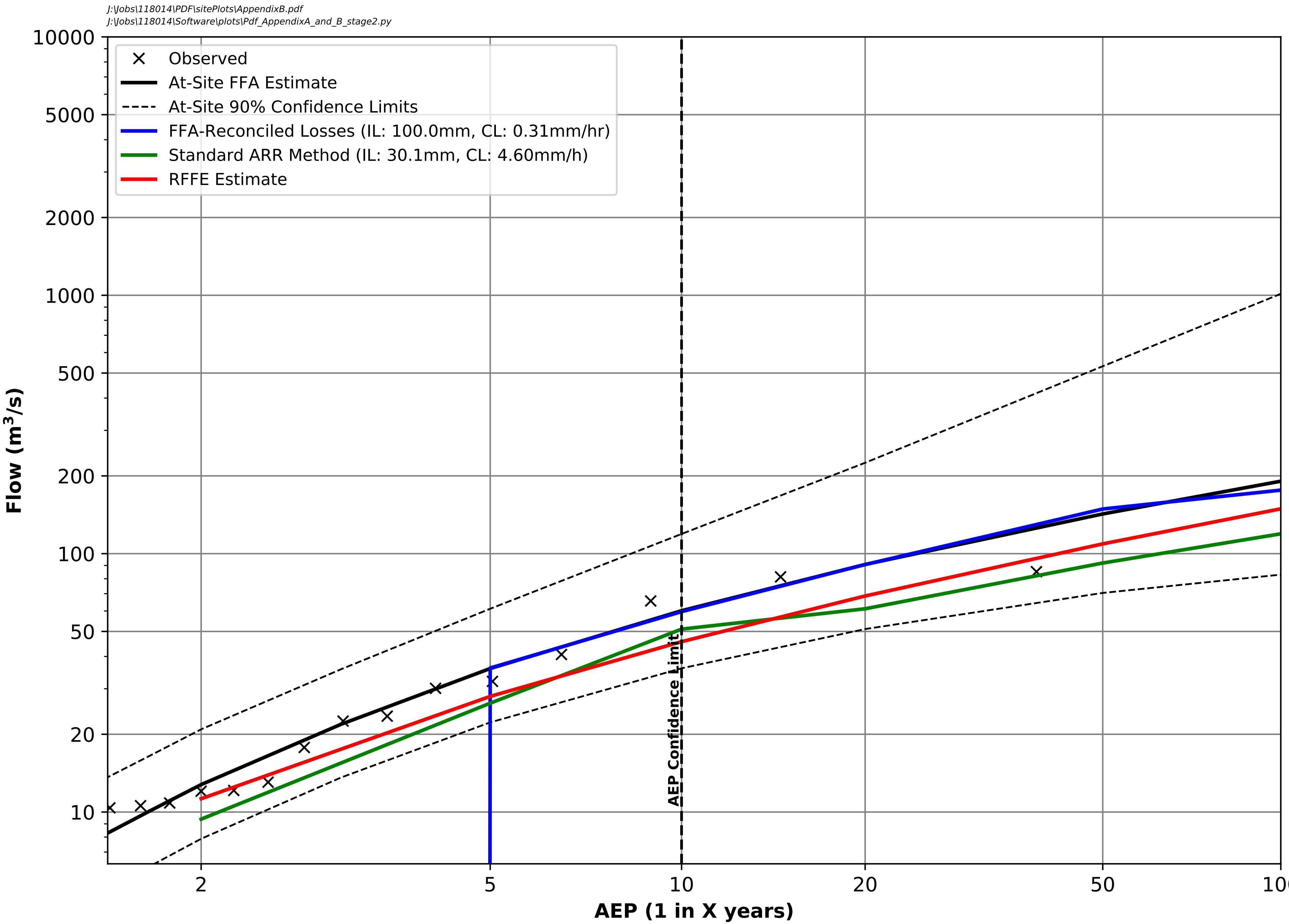


METHOD COMPARISON
WIAGDON - 421106 [G2]

APPENDIX B59



METHOD COMPARISON
STROMLO - 421104 [G3]

APPENDIX B60

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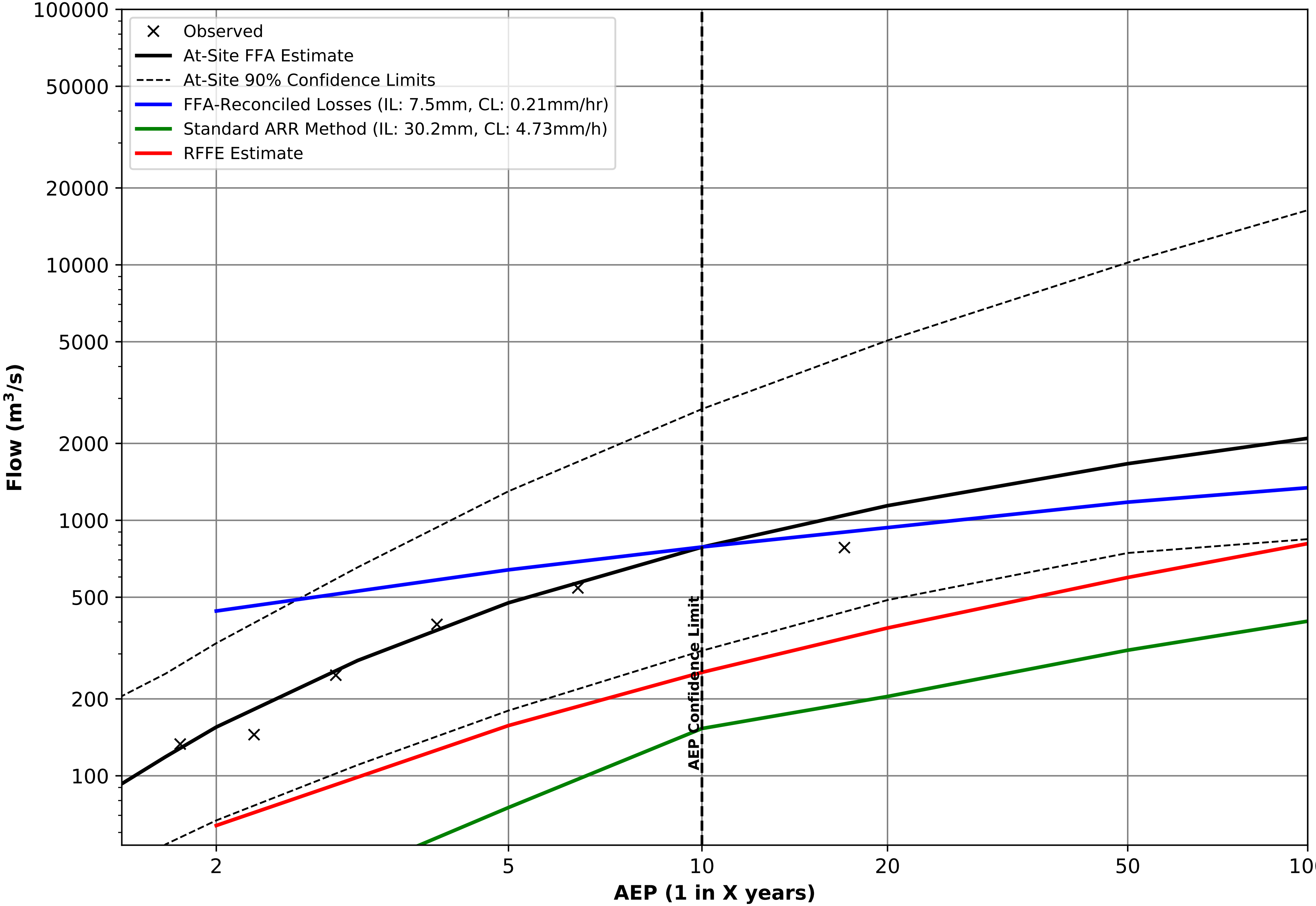

METHOD COMPARISON
U/S BEN CHIFLEY DAM - 421101 [G4]

APPENDIX B61

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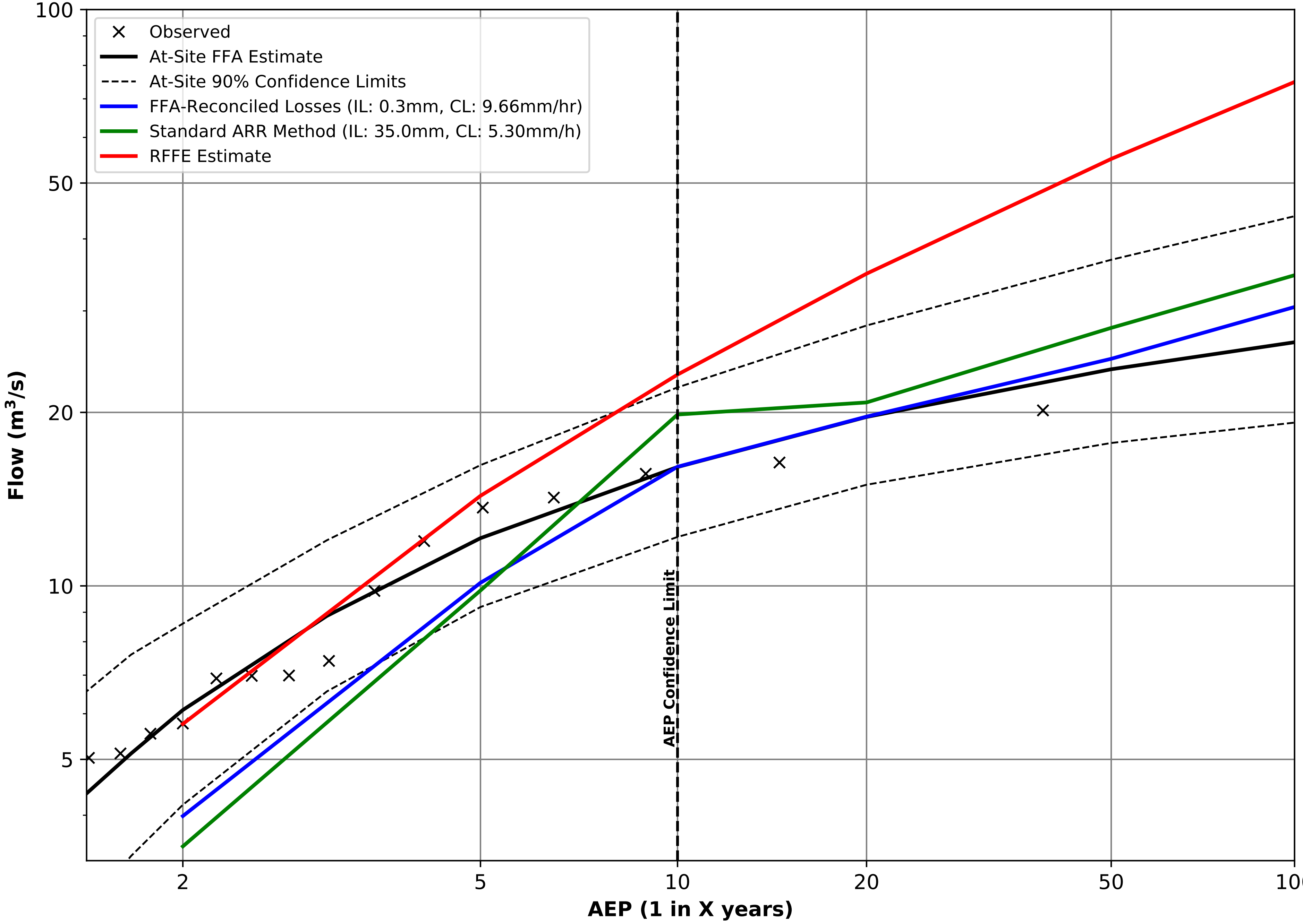

METHOD COMPARISON
DAM SITE - 421034 [G5]

APPENDIX B62

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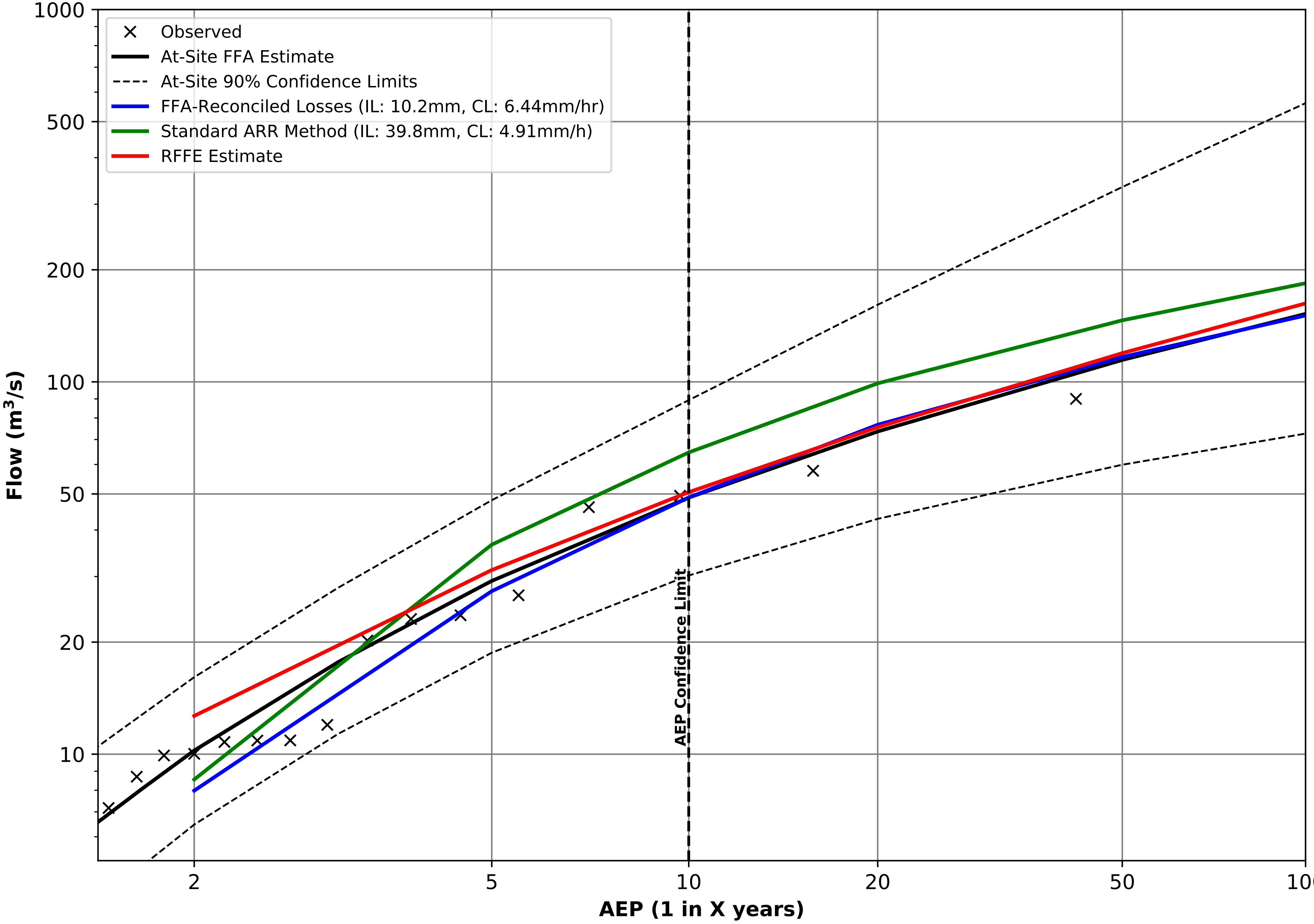
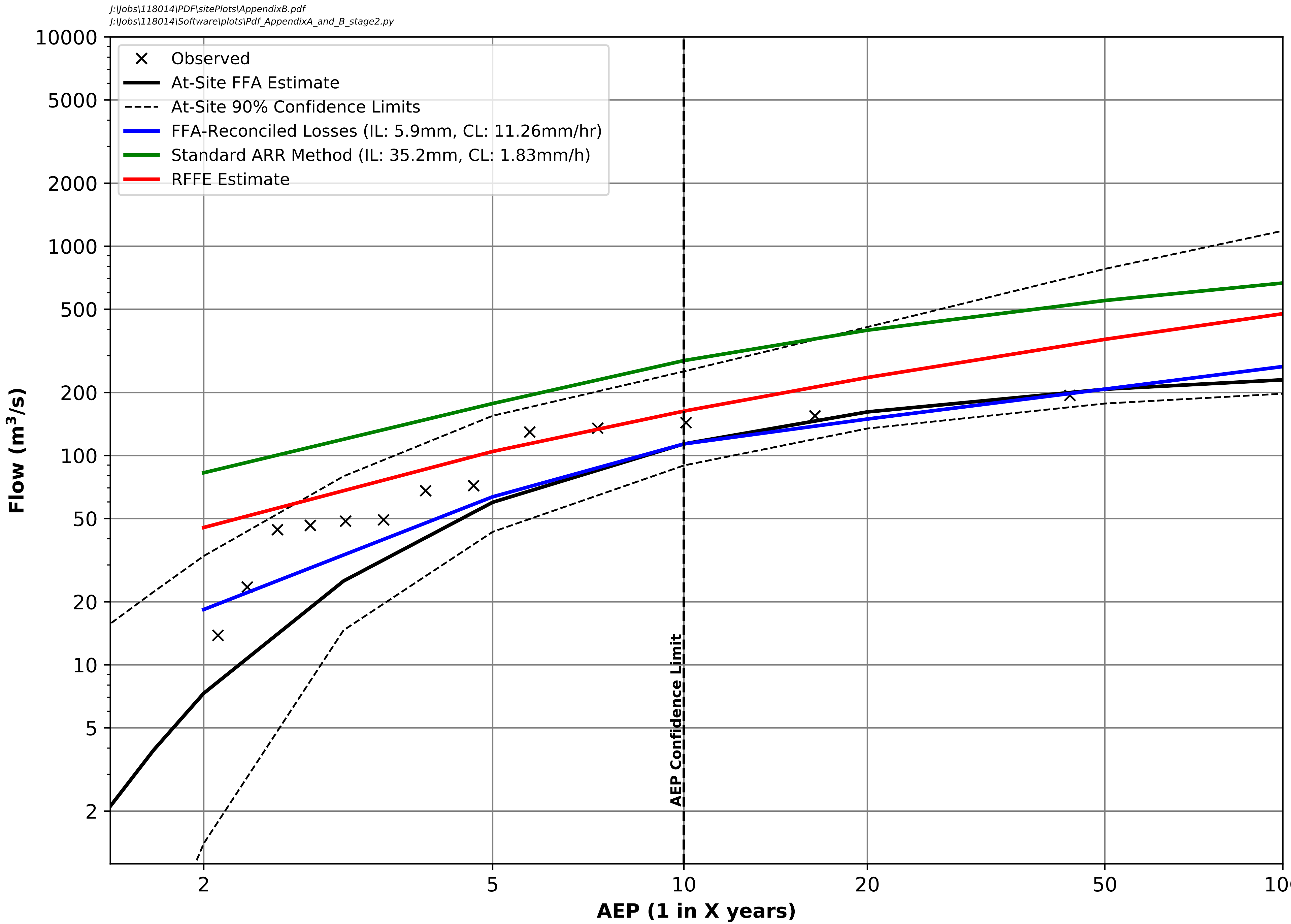


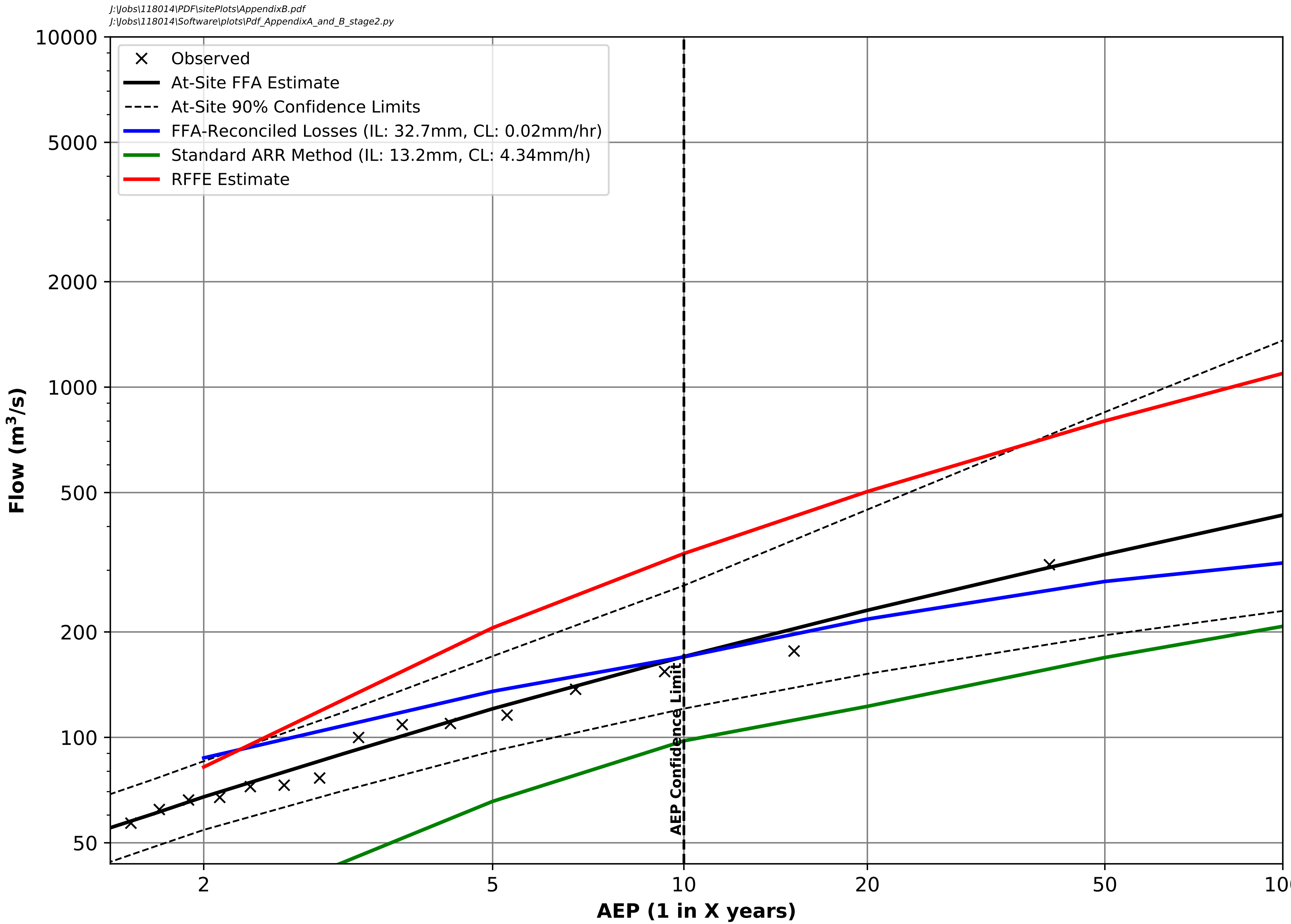
METHOD COMPARISON
BELOW DAM SITE - 421036 [G6]

APPENDIX B63



SAXA CROSSING - 421068 [G7]
METHOD COMPARISON

APPENDIX B64



METHOD COMPARISON
HILL END - 421066 [G8]

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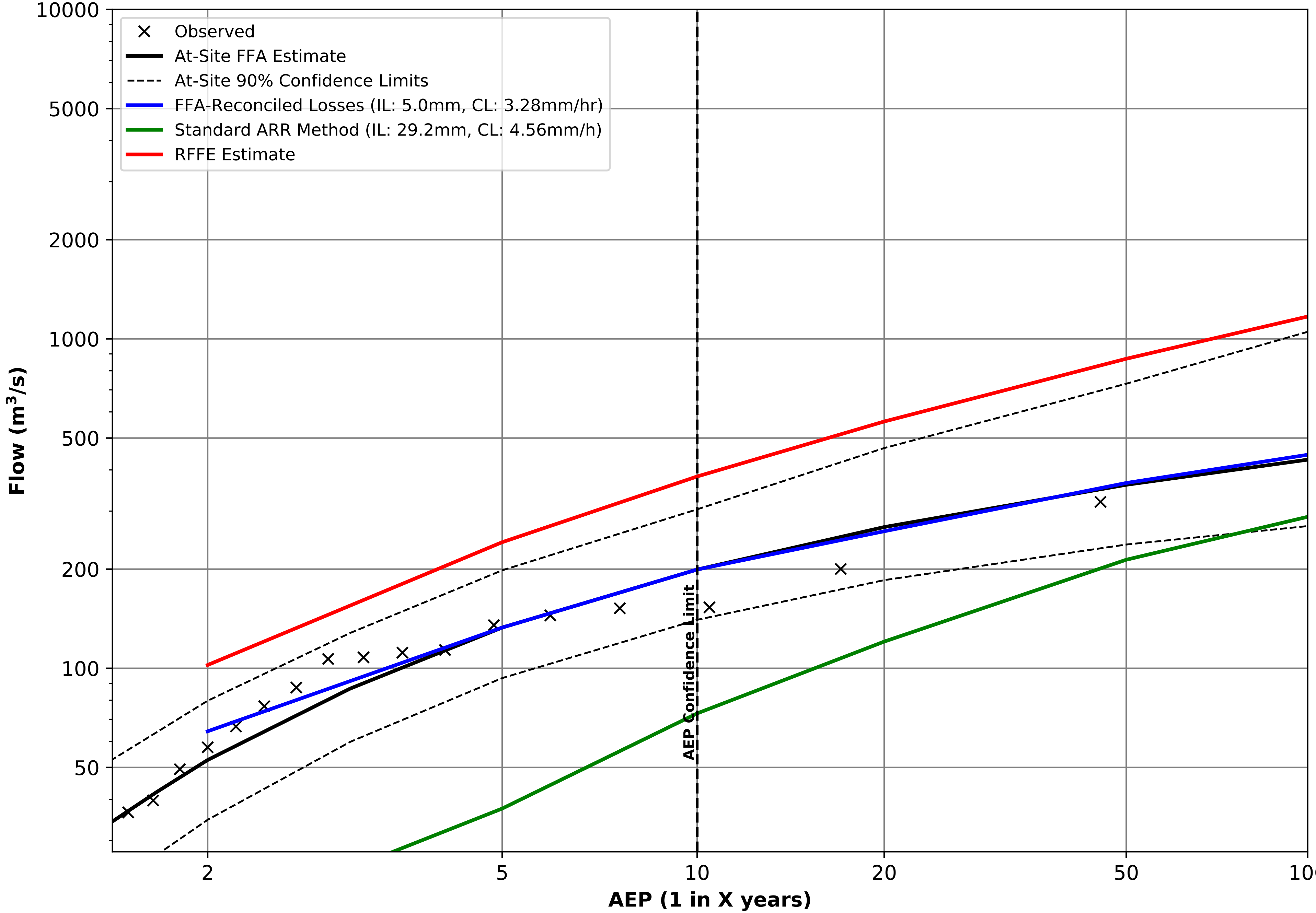

METHOD COMPARISON
KENNYS CK RD - 412096 [G9]

APPENDIX B66

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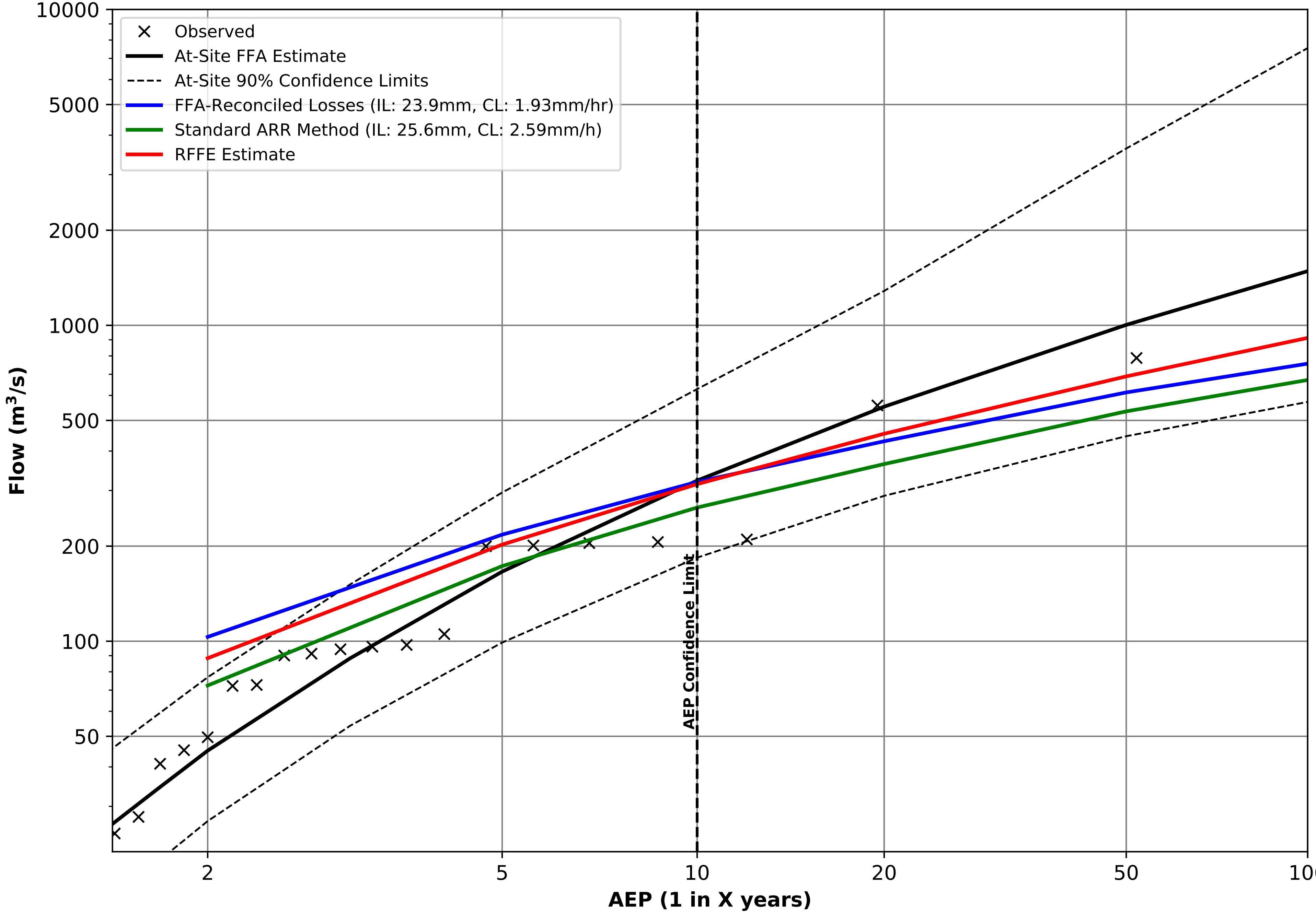
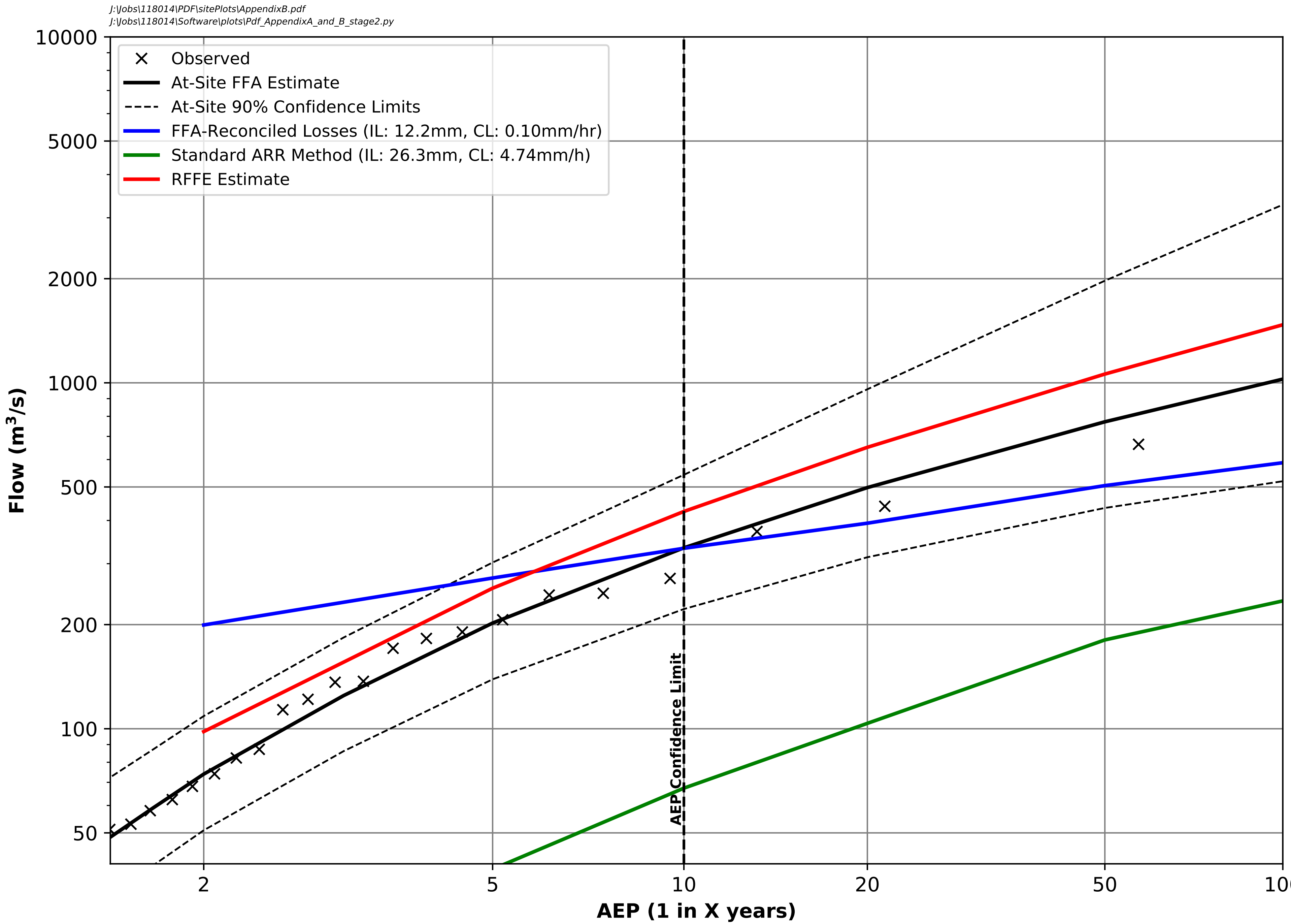
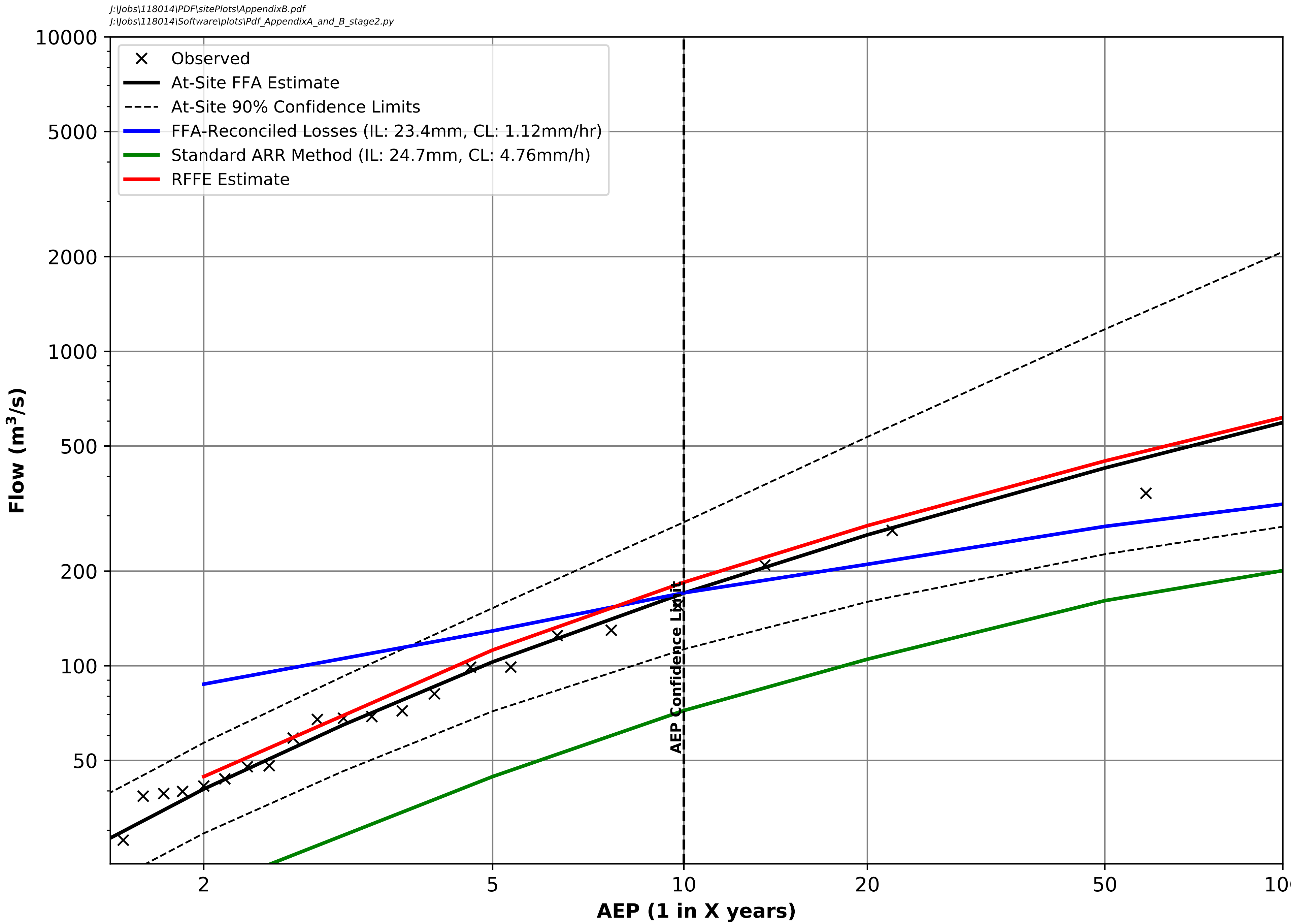


METHOD COMPARISON
OBLEY NO.2 - 421048 [G10]



METHOD COMPARISON
TUENA - 412083 [G11]

APPENDIX B68



METHOD COMPARISON
NEAR NEVILLE - 412081 [G12]

APPENDIX B69

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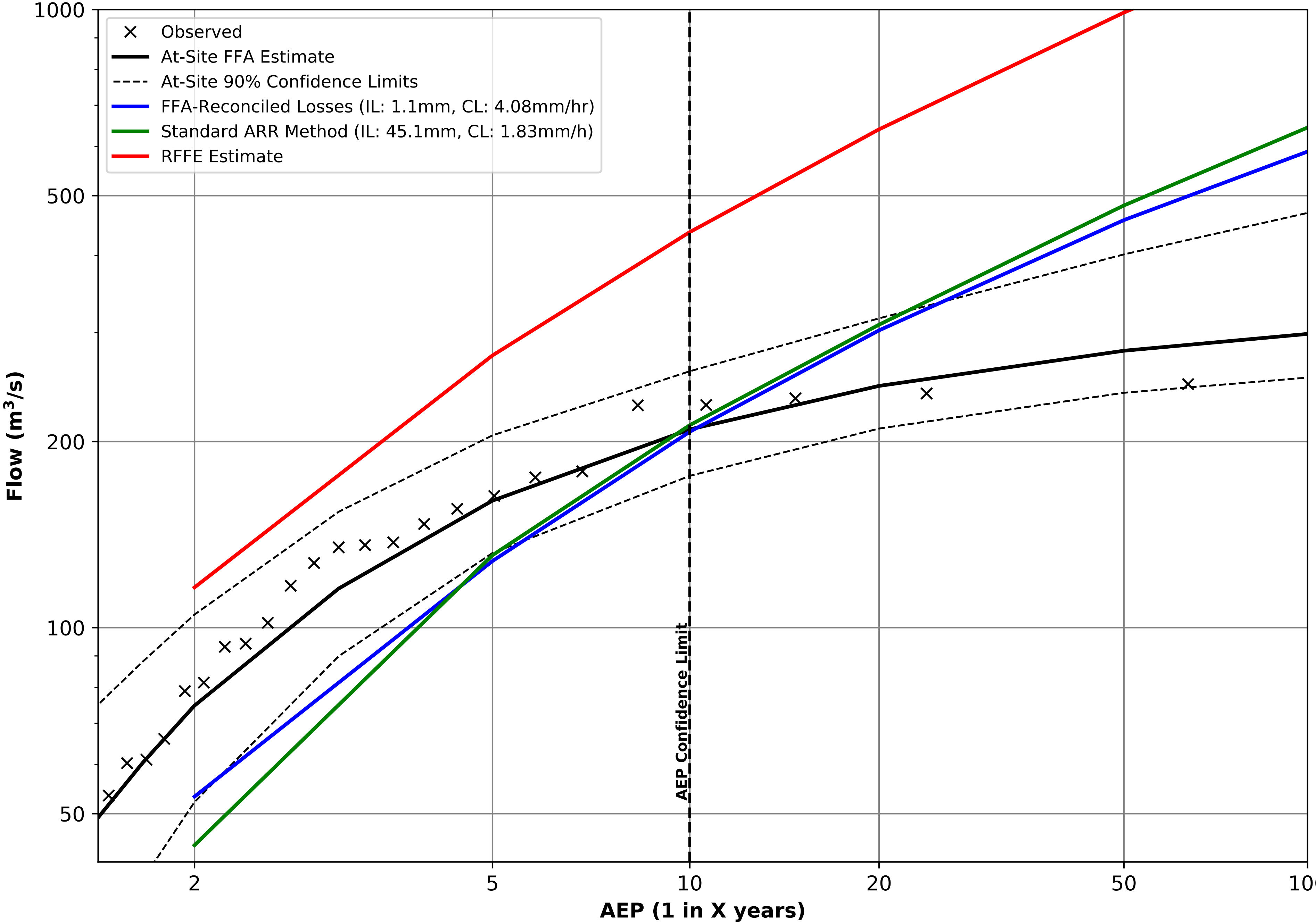

METHOD COMPARISON
RAWSONVILLE - 421055 [G13]

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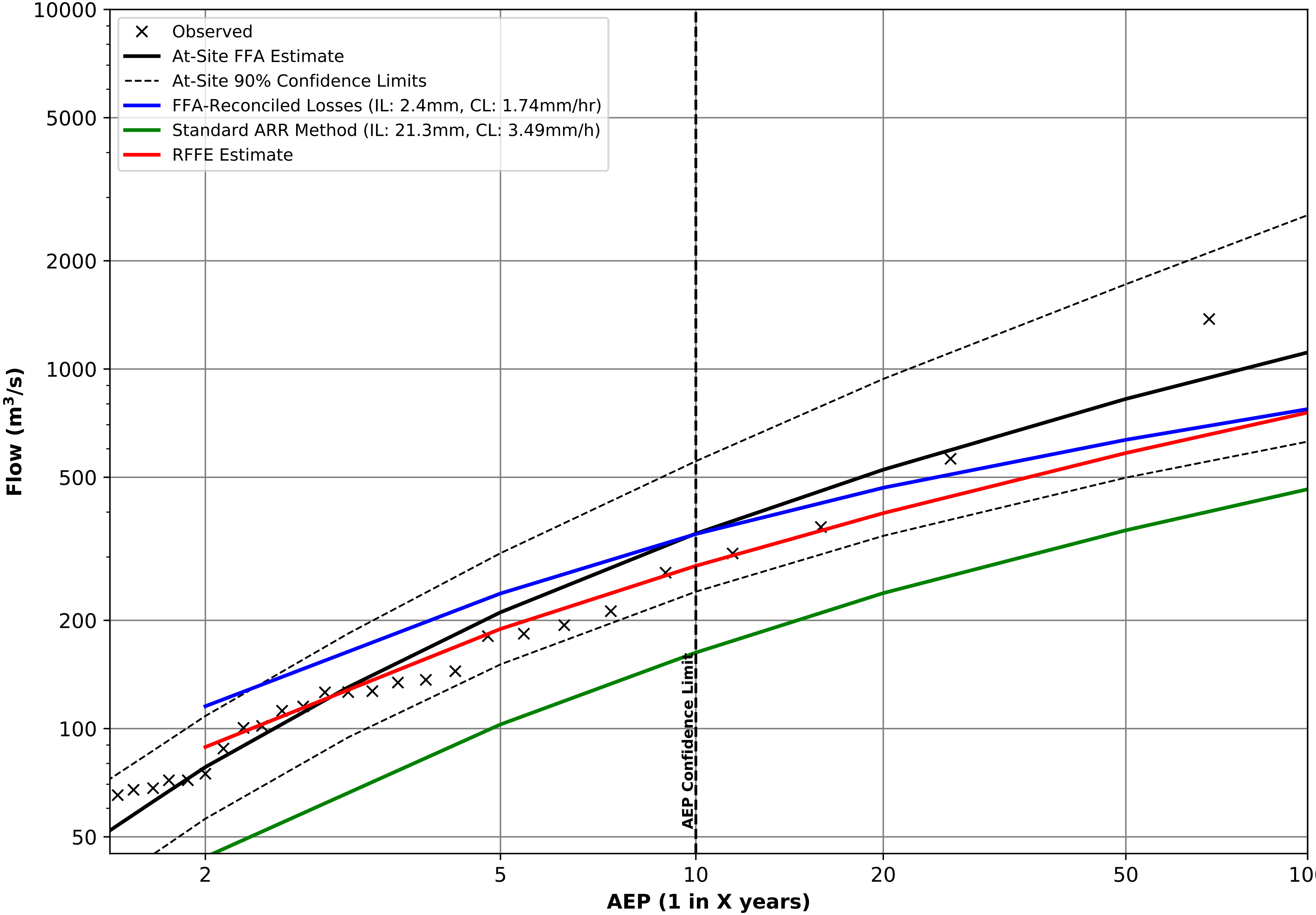

METHOD COMPARISON
GUNNING - 412063 [G14]

APPENDIX B71

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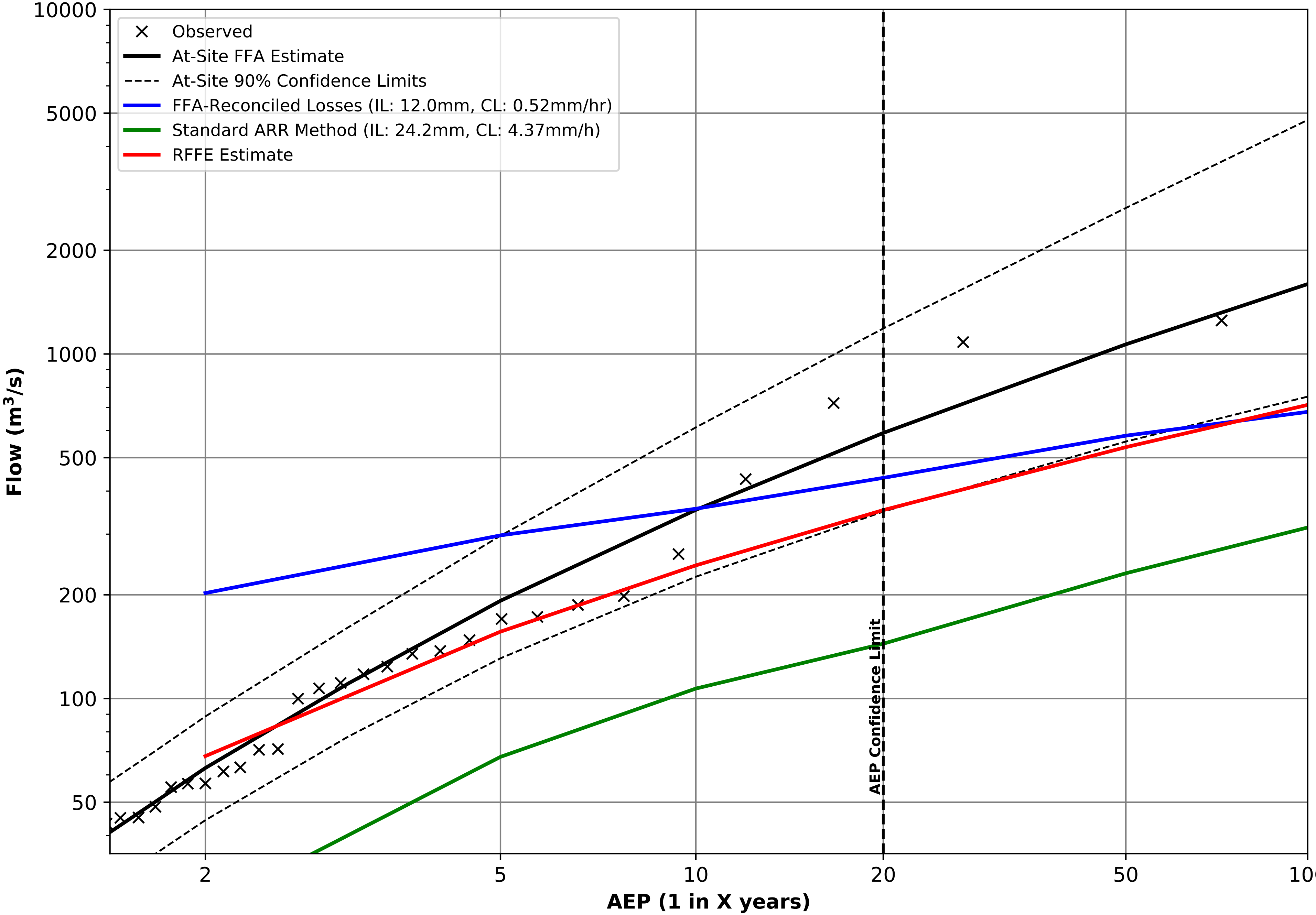
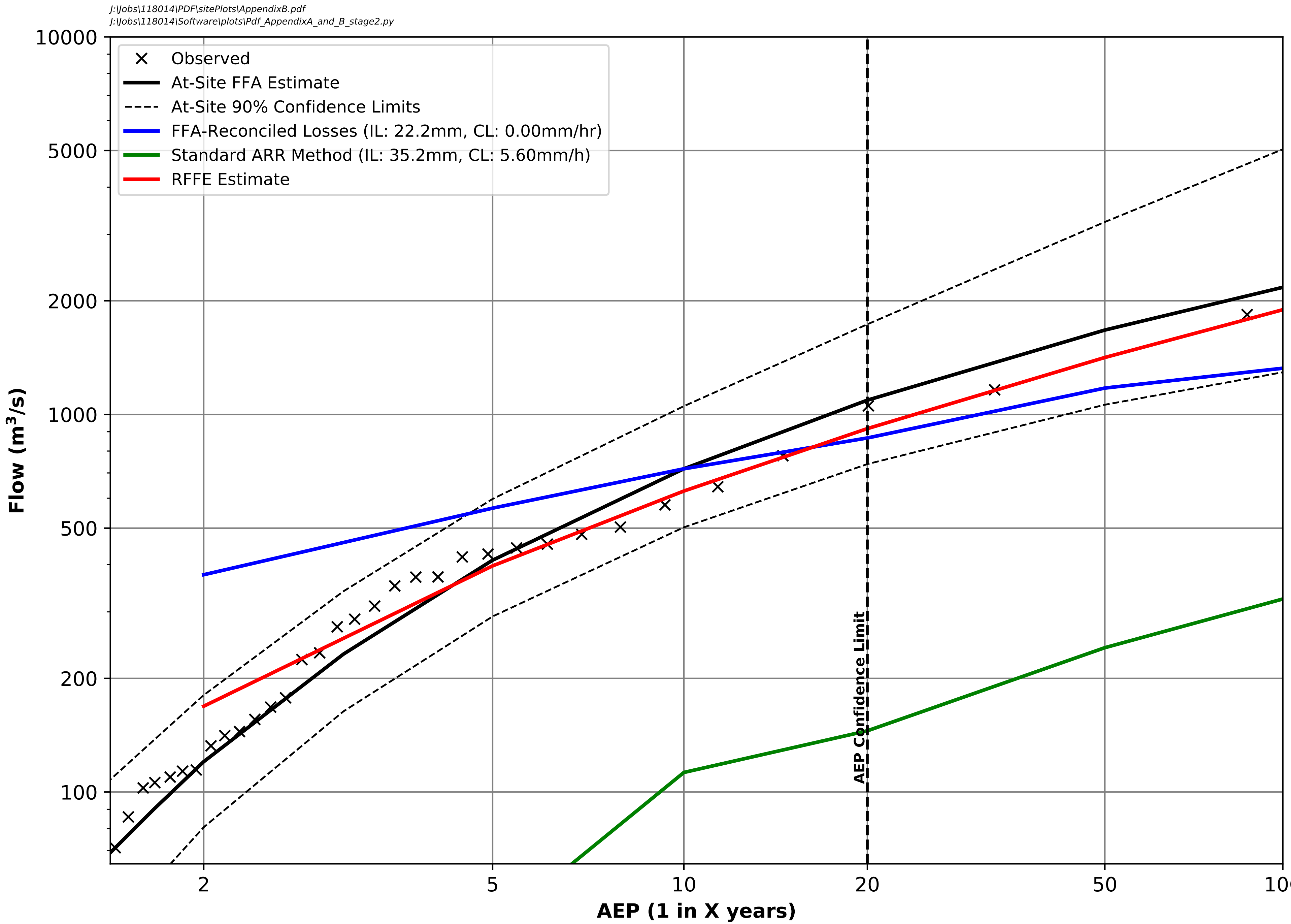
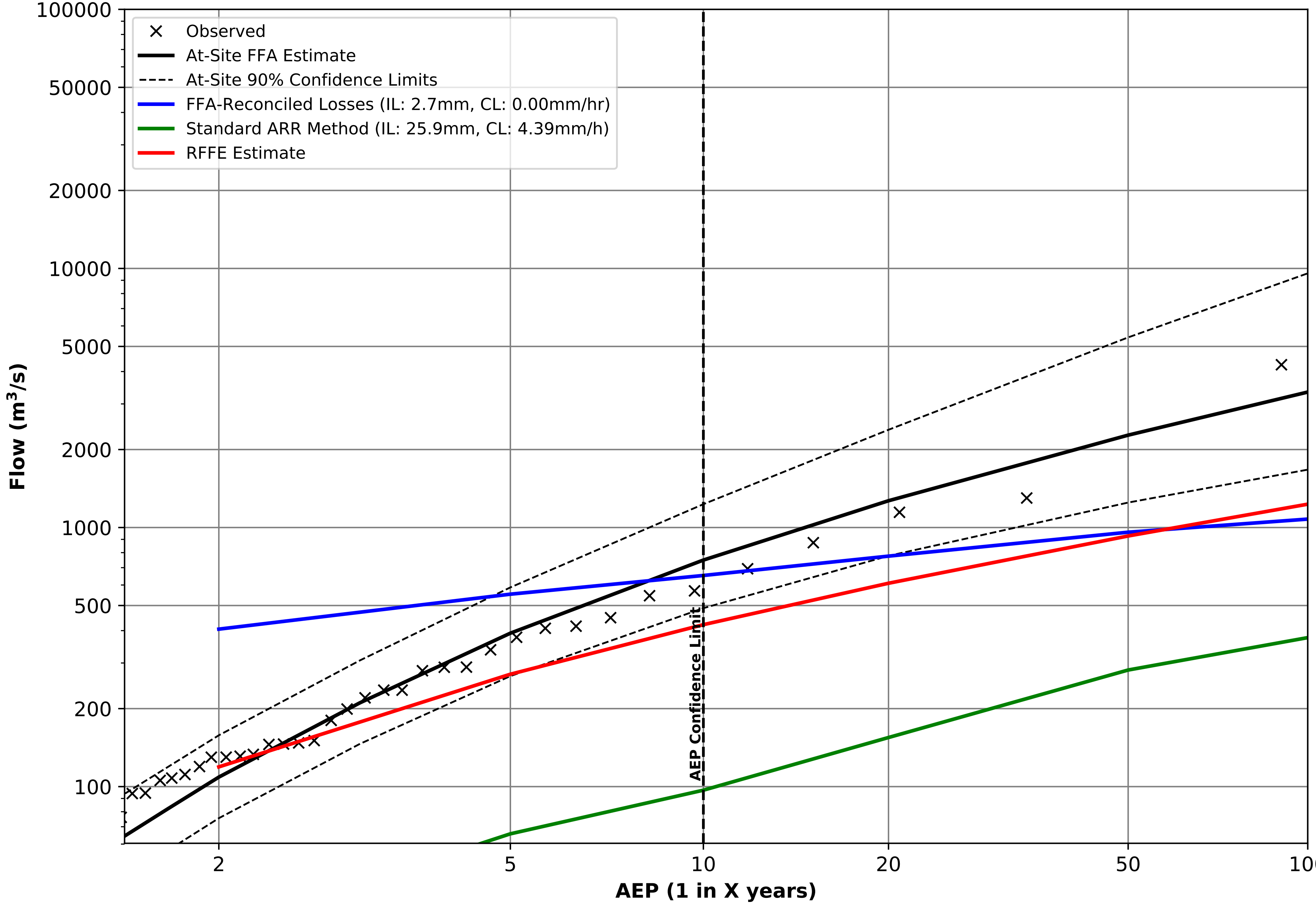


METHOD COMPARISON
MOLONG - 421050 [G15]



METHOD COMPARISON
SOFALA - 421026 [G16]



METHOD COMPARISON
NARRAWA NORTH - 412050 [G17]

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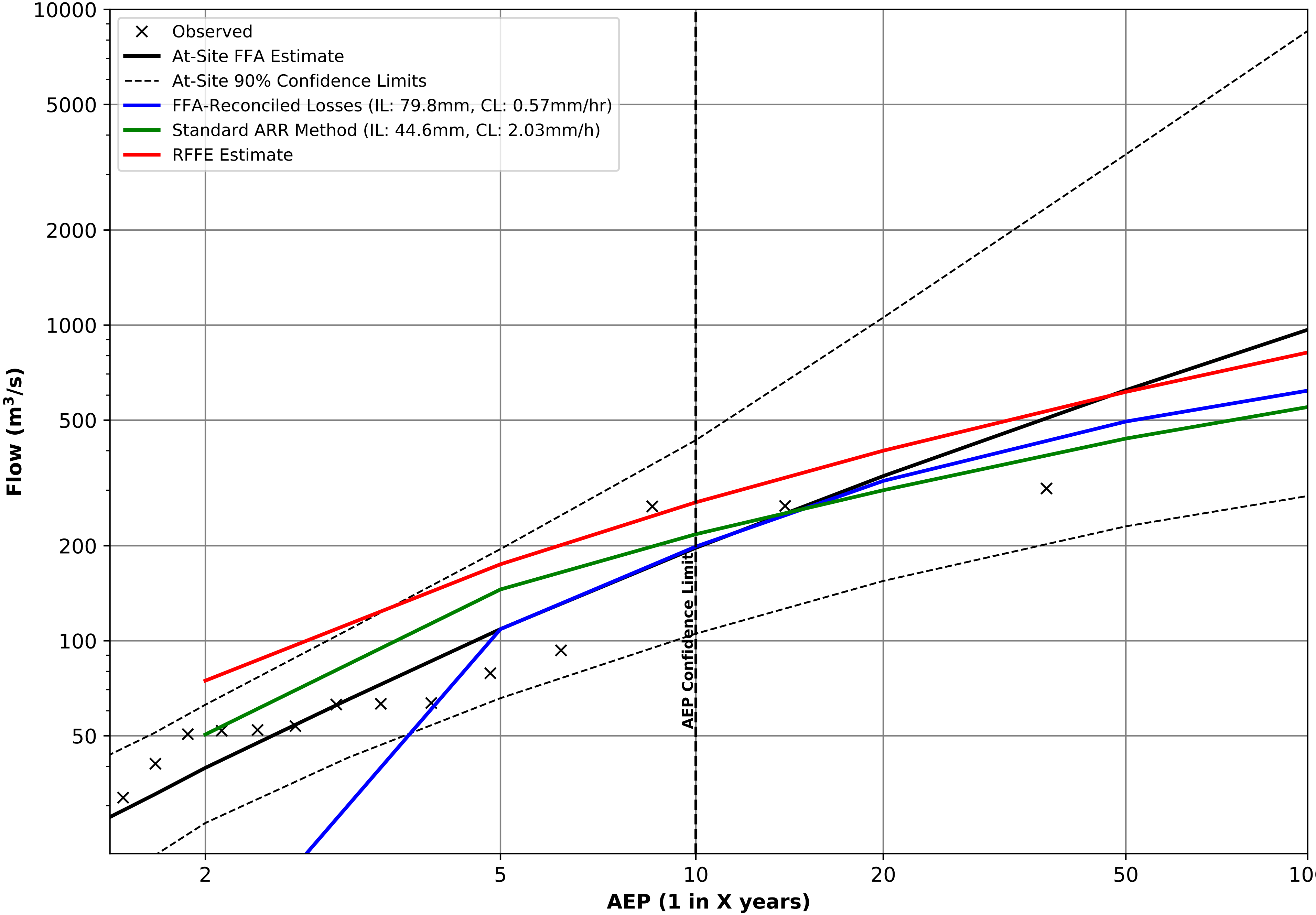
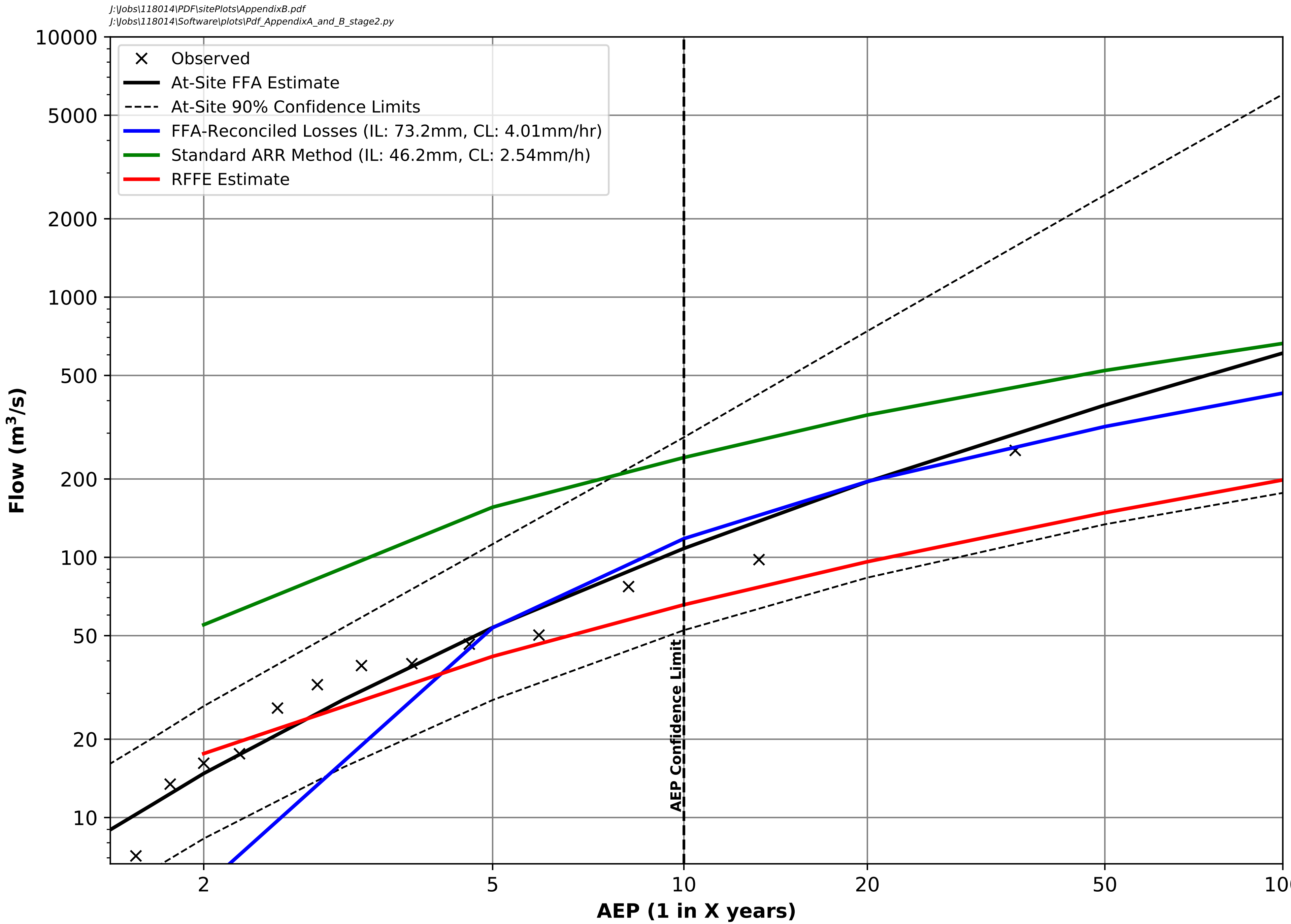


METHOD COMPARISON
NEILREX - 420012 [G18]

APPENDIX B75



METHOD COMPARISON
BEARBUNG - 420010 [G19]

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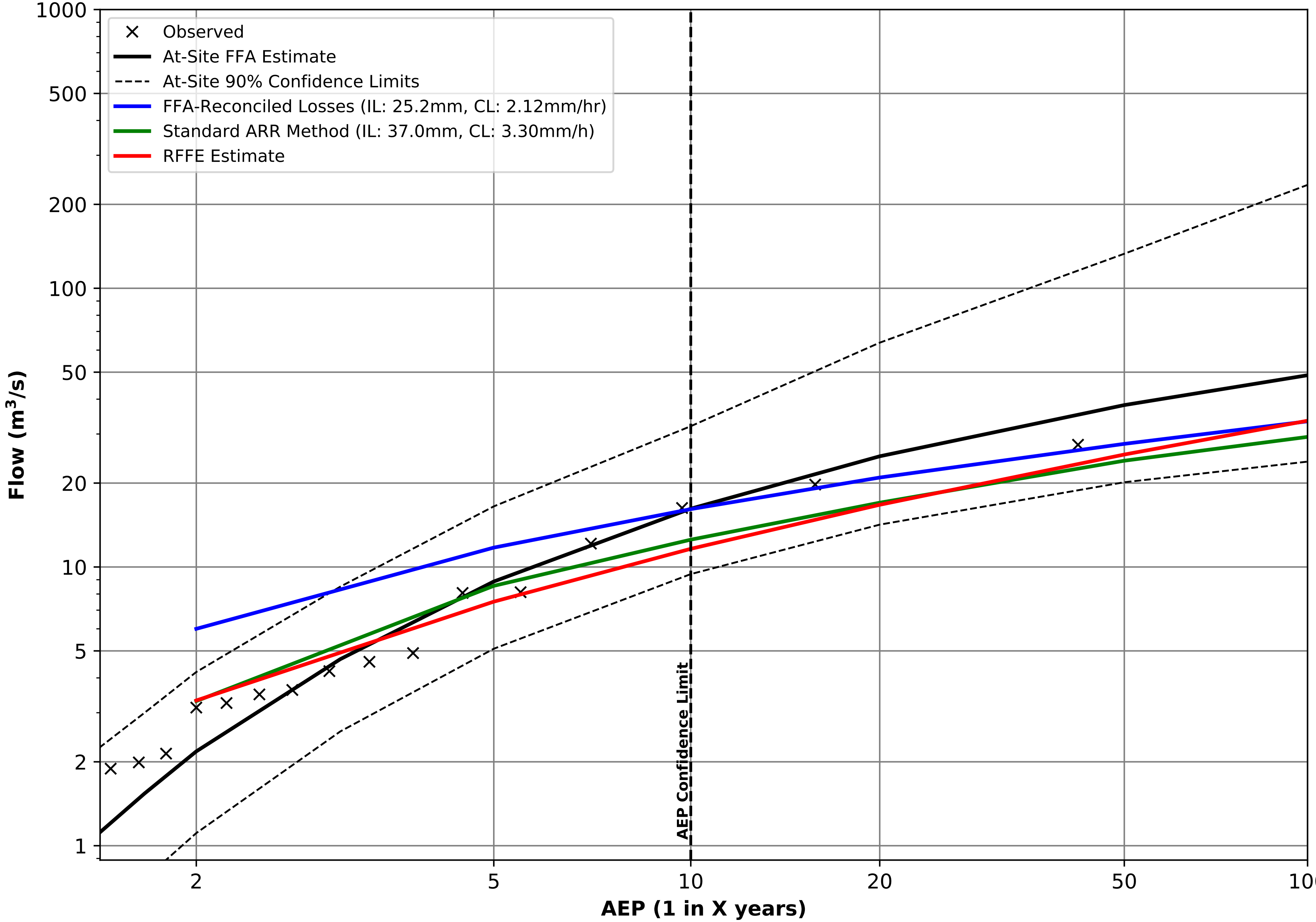

METHOD COMPARISON
POKOLBIN SITE 4 - 210069 [H1]

APPENDIX B77

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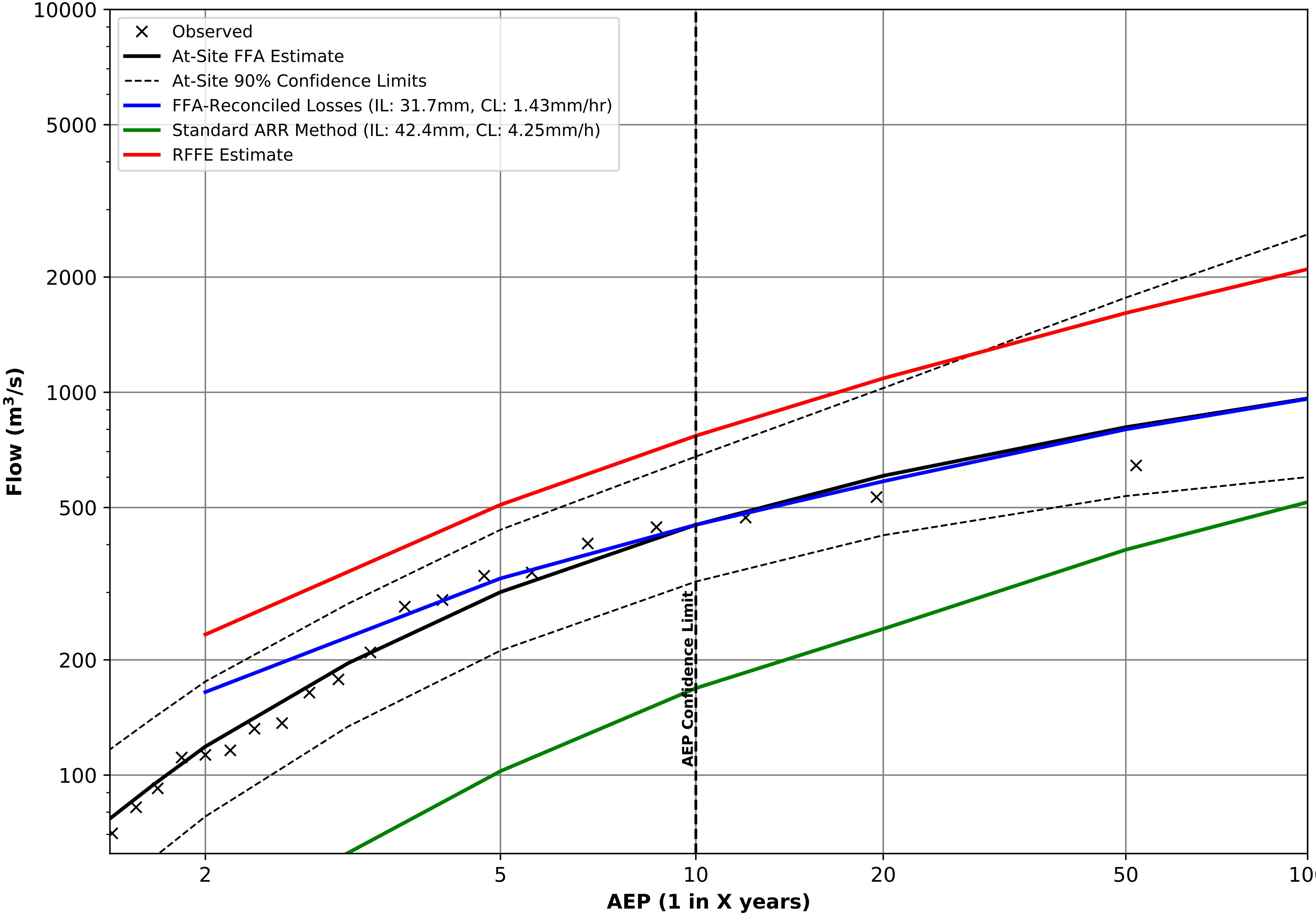
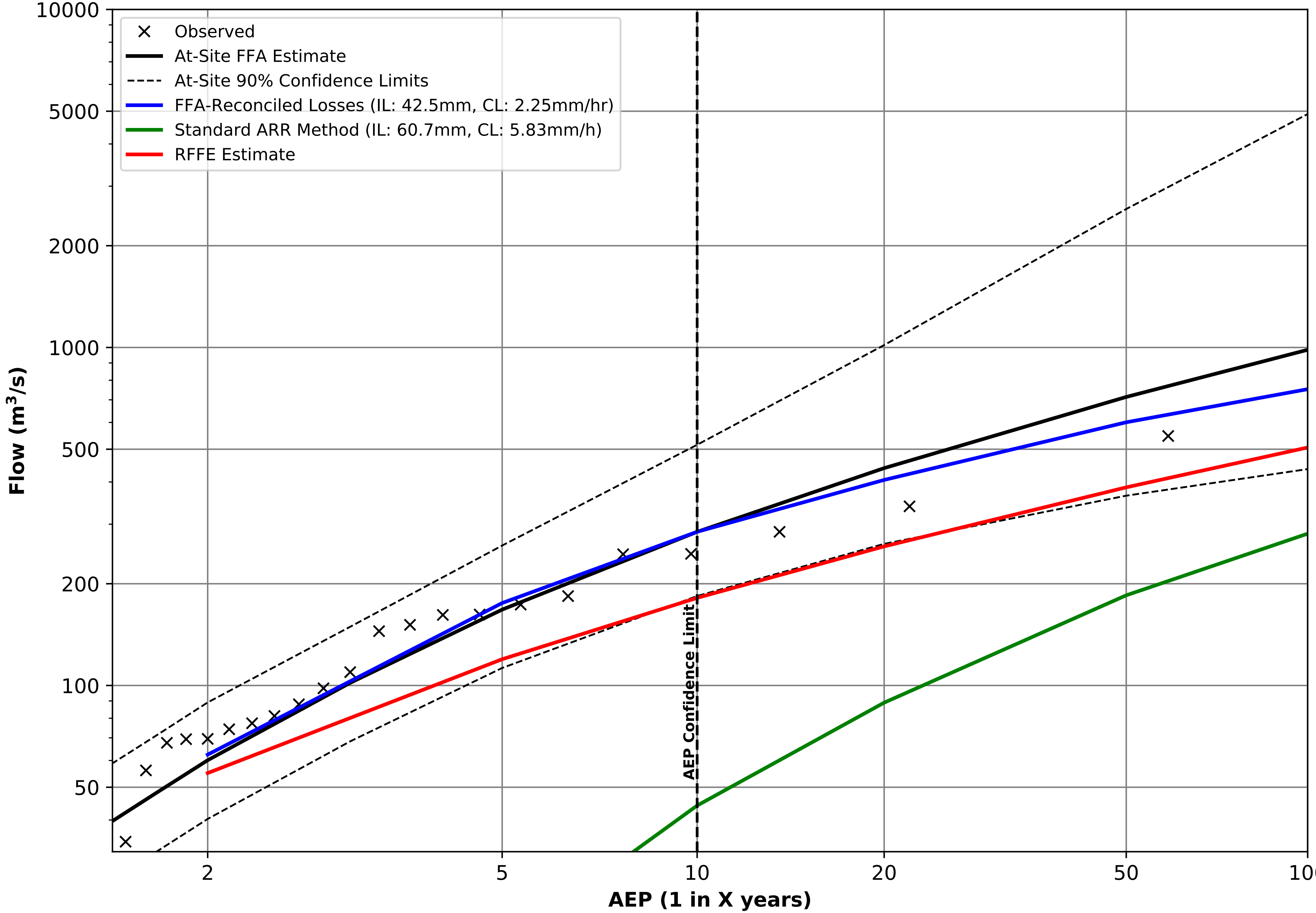
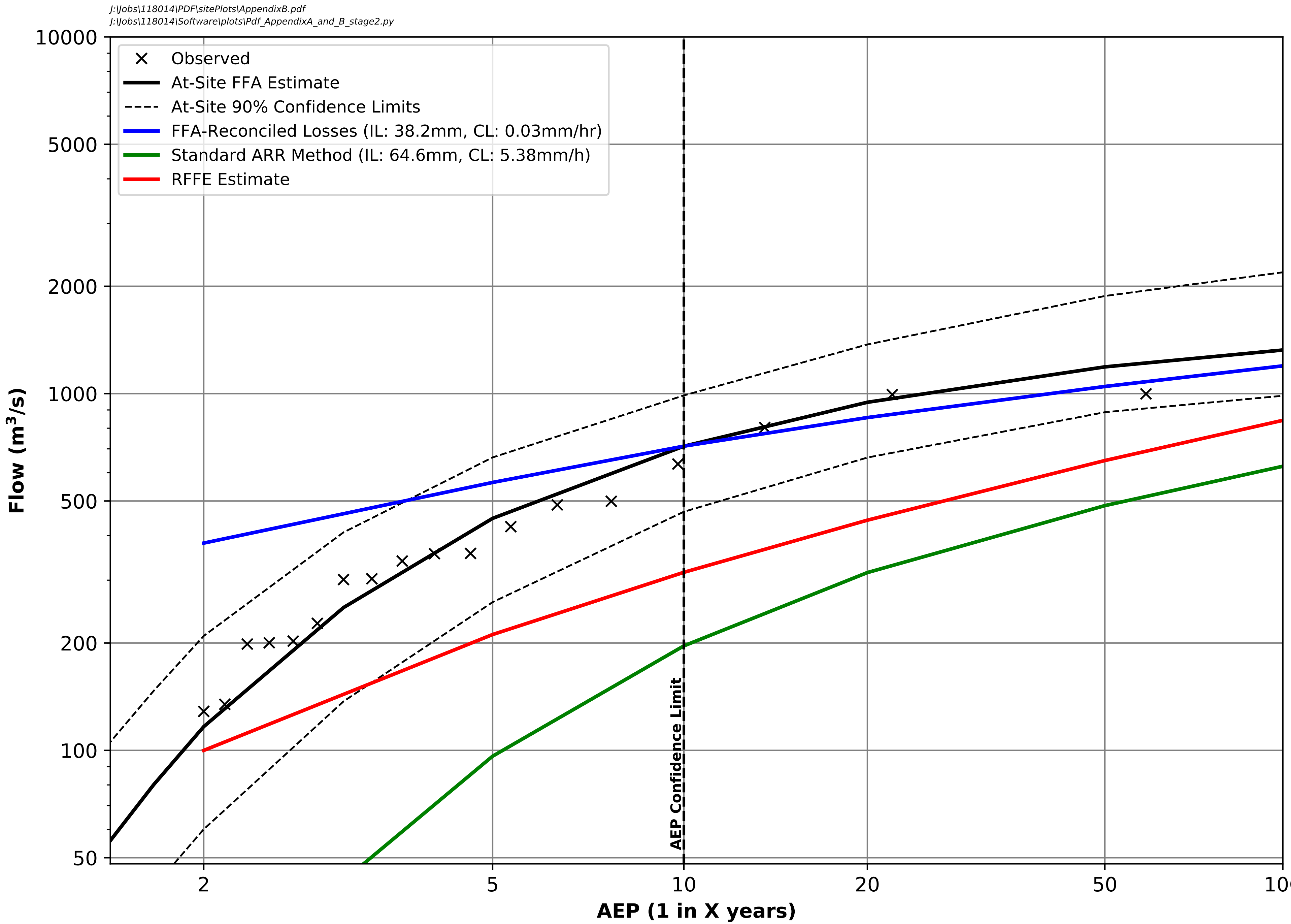


METHOD COMPARISON
MEASURING WEIR - 208027 [H2]

APPENDIX B78



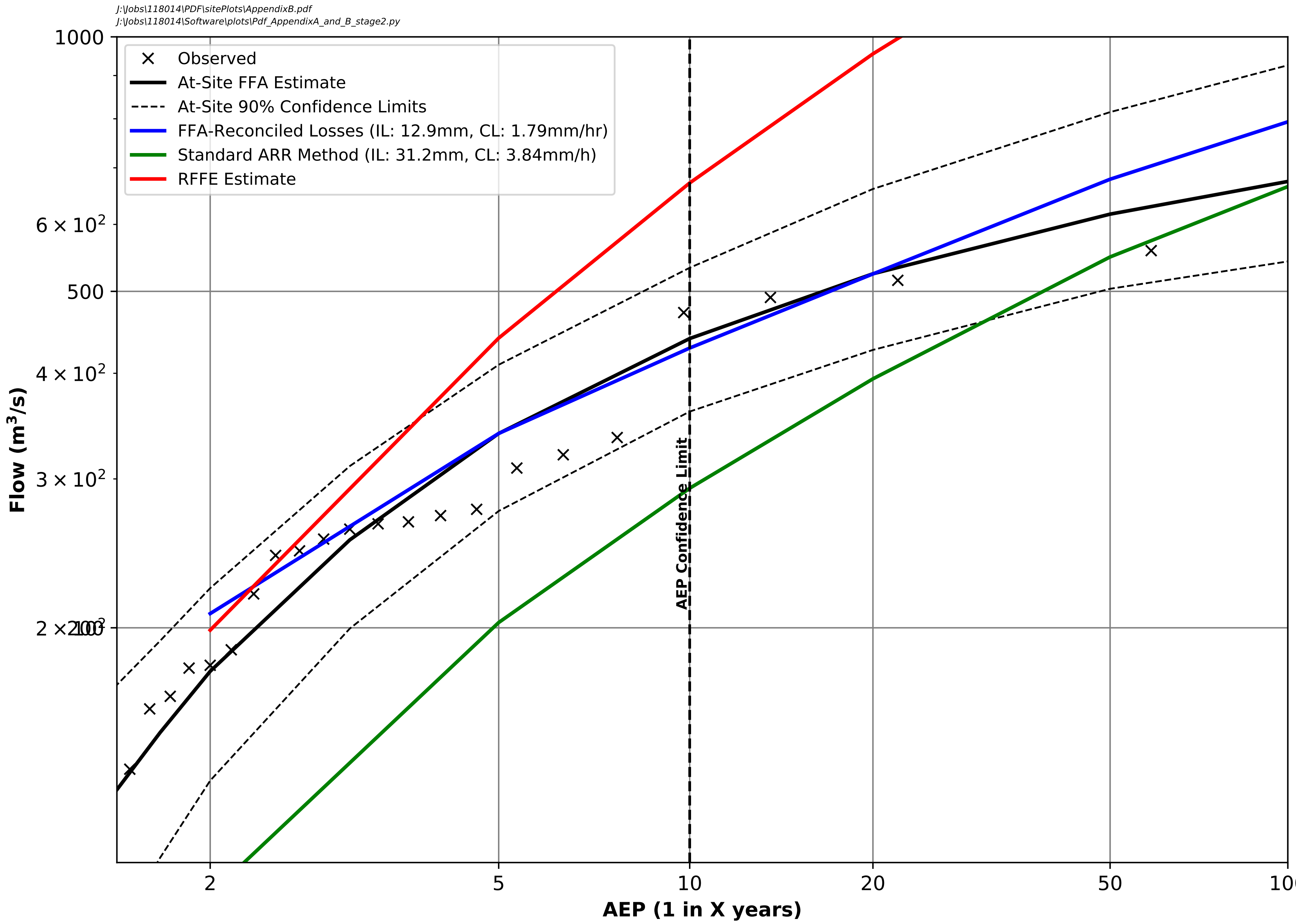
METHOD COMPARISON
FORBESDALE (CAUSEWAY) - 208026 [H3]



METHOD COMPARISON

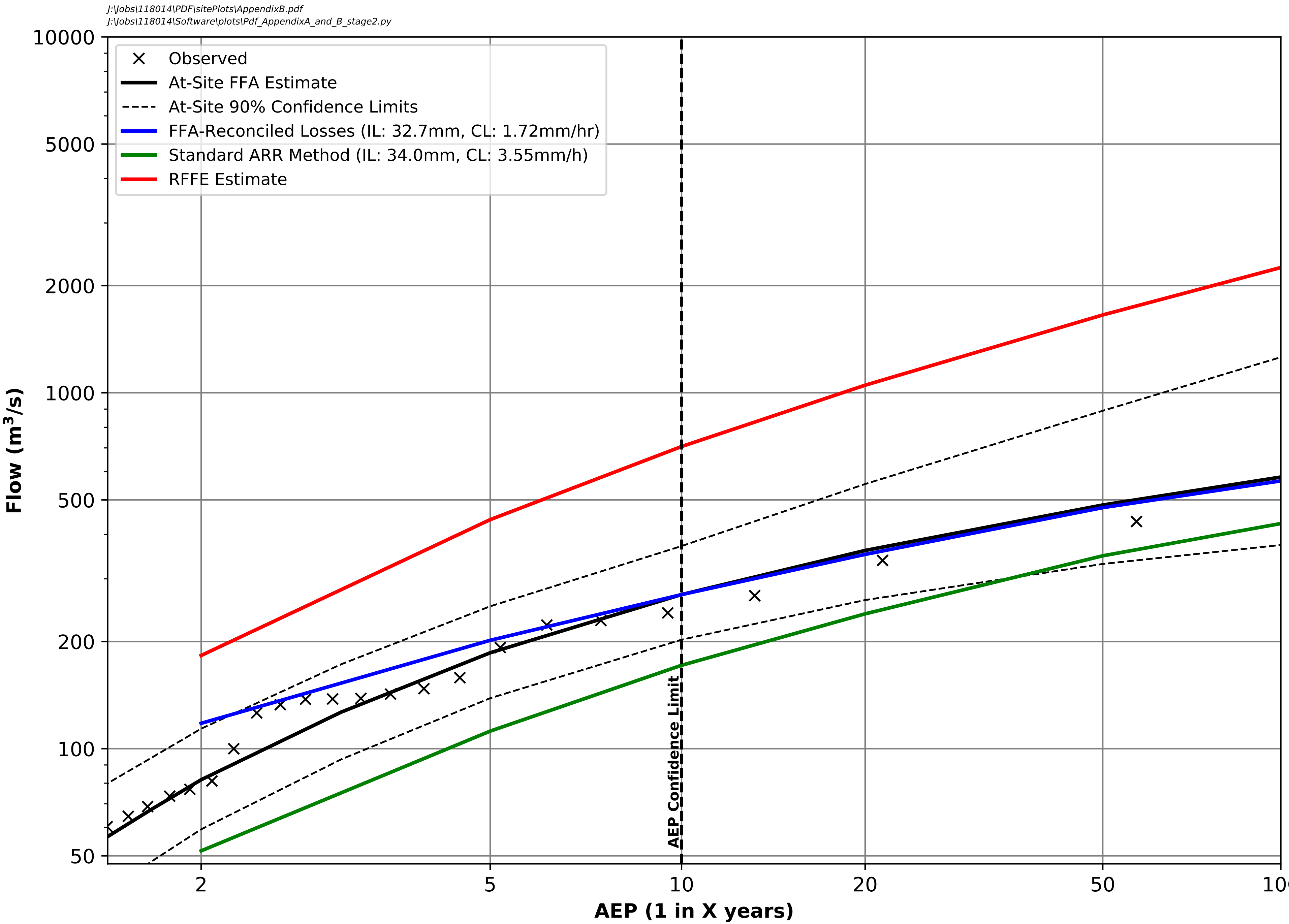
MOUNT SEAVIEW - 207015 [H4]

APPENDIX B80



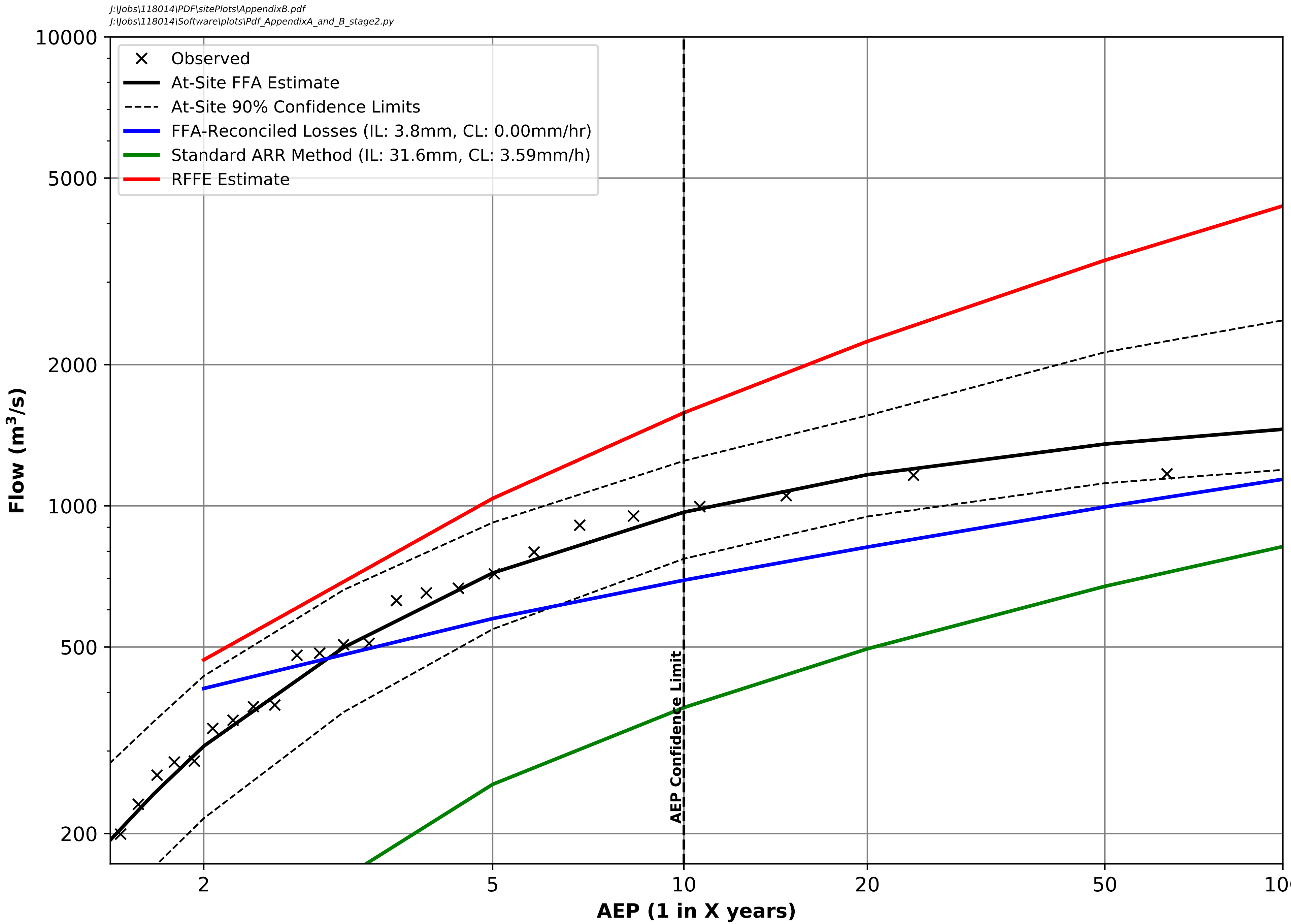
METHOD COMPARISON
MONKERAI - 209001 [H5]

APPENDIX B81



METHOD COMPARISON
D/S BACK R JCTN - 208024 [H6]

APPENDIX B82



METHOD COMPARISON
DAM SITE - 209018 [H7]

APPENDIX B83

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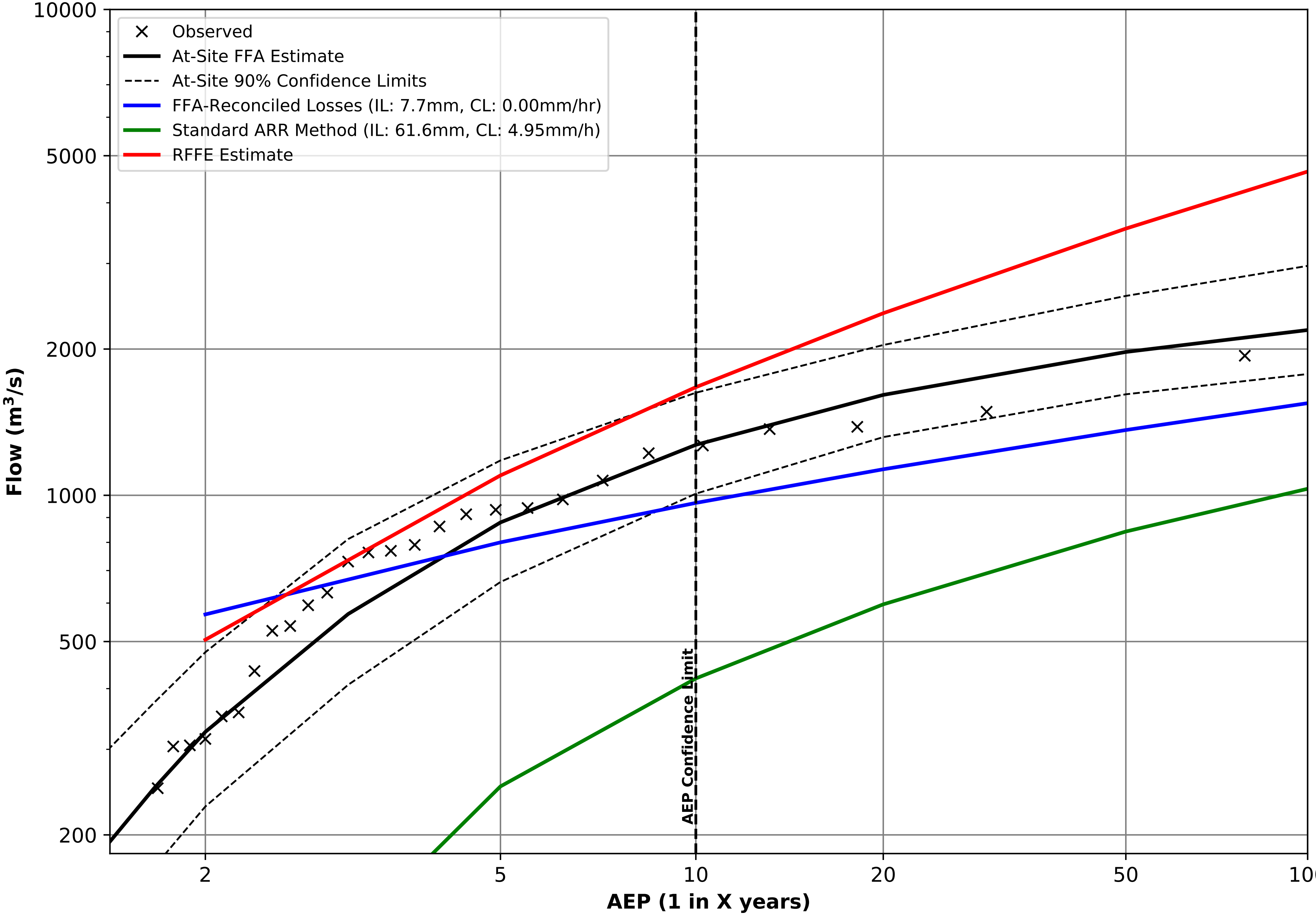
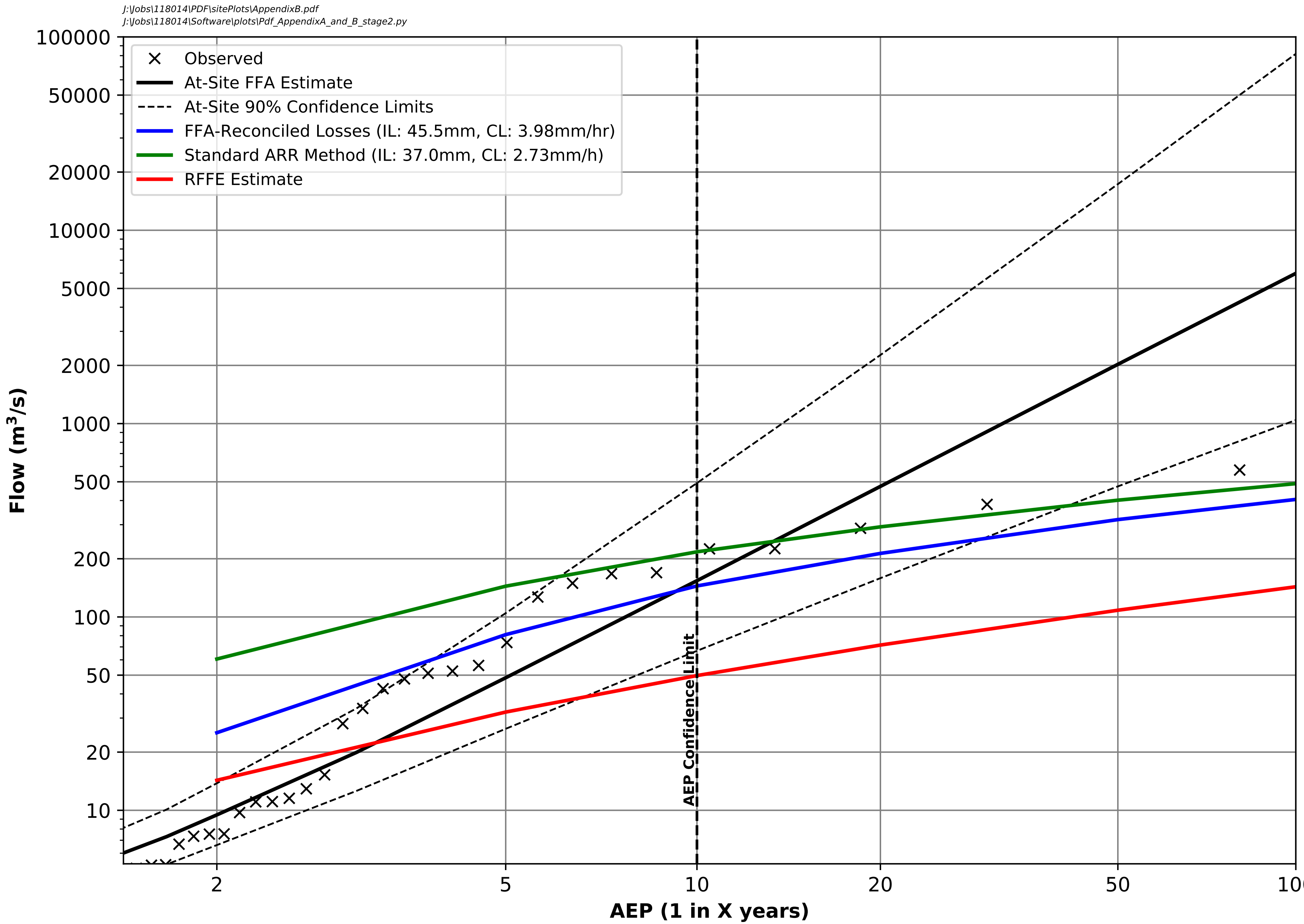
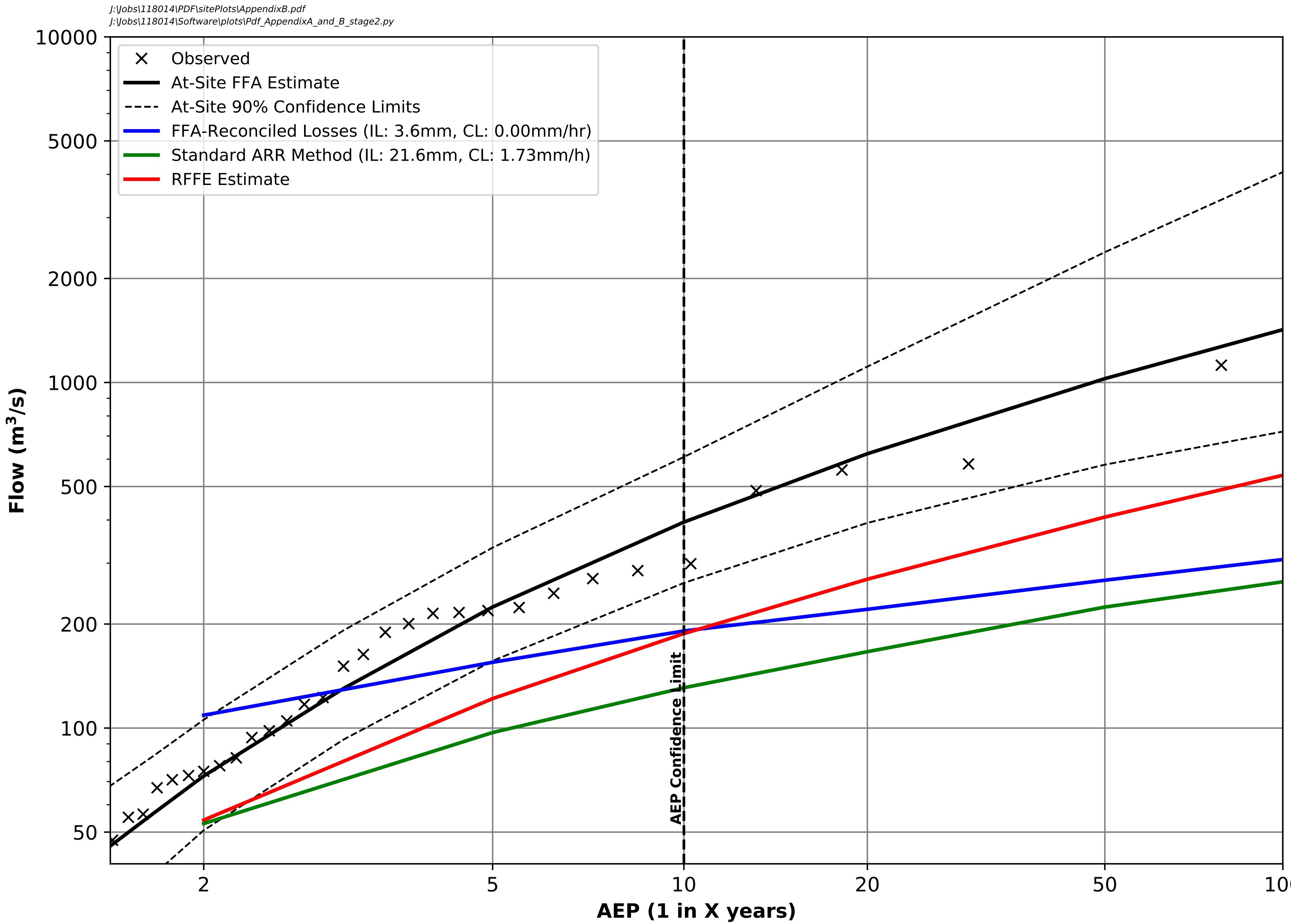


METHOD COMPARISON
BIRDWOOD(FILLY FLAT) - 207006 [H8]

APPENDIX B84



METHOD COMPARISON
THE ROCKS NO.2 - 210084 [H9]



METHOD COMPARISON
U/S GLENDON BROOK - 210080 [H10]

APPENDIX B86

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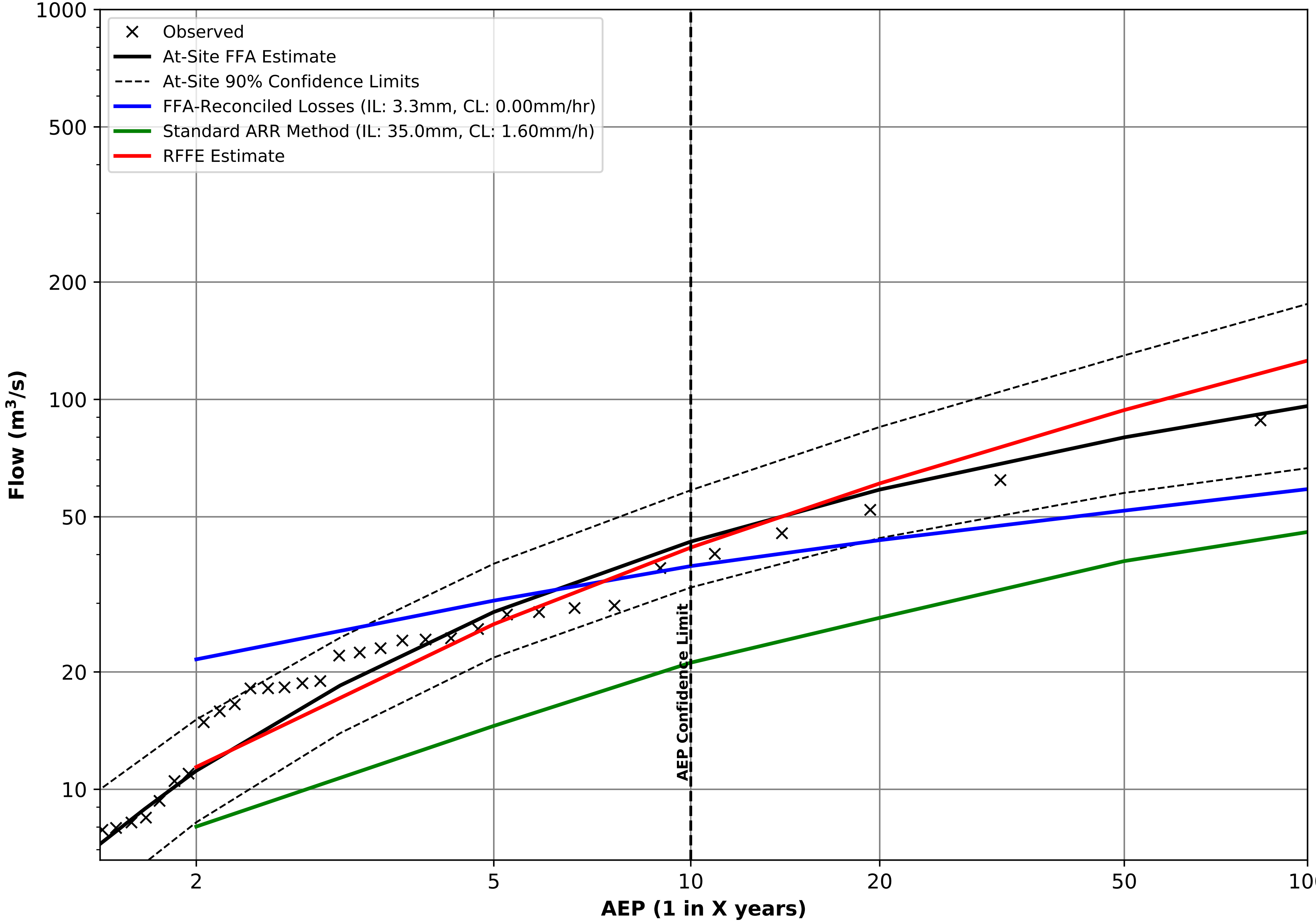

METHOD COMPARISON
LIDDELL - 210076 [H11]

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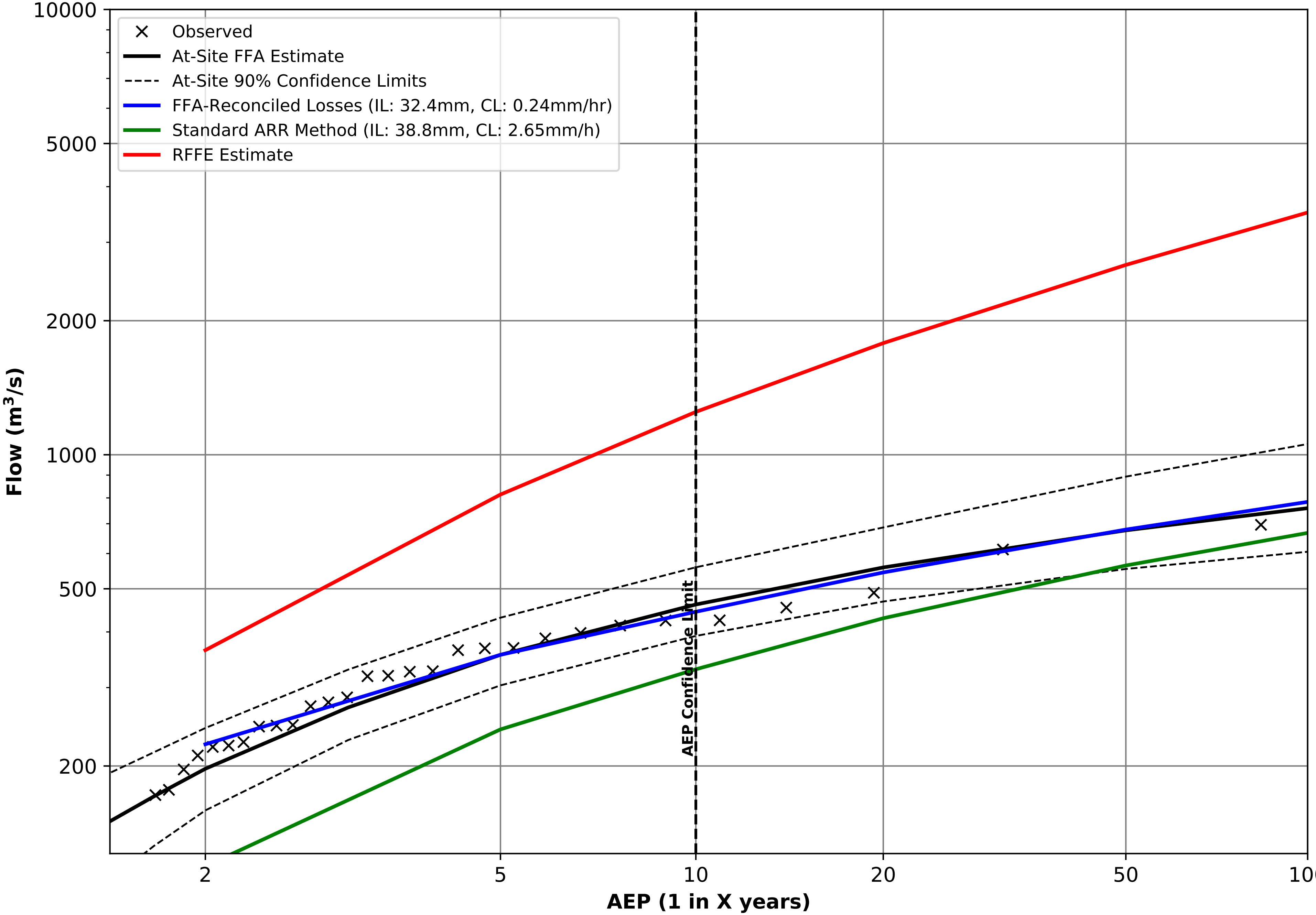

METHOD COMPARISON
CROSSING - 209002 [H12]

APPENDIX B88

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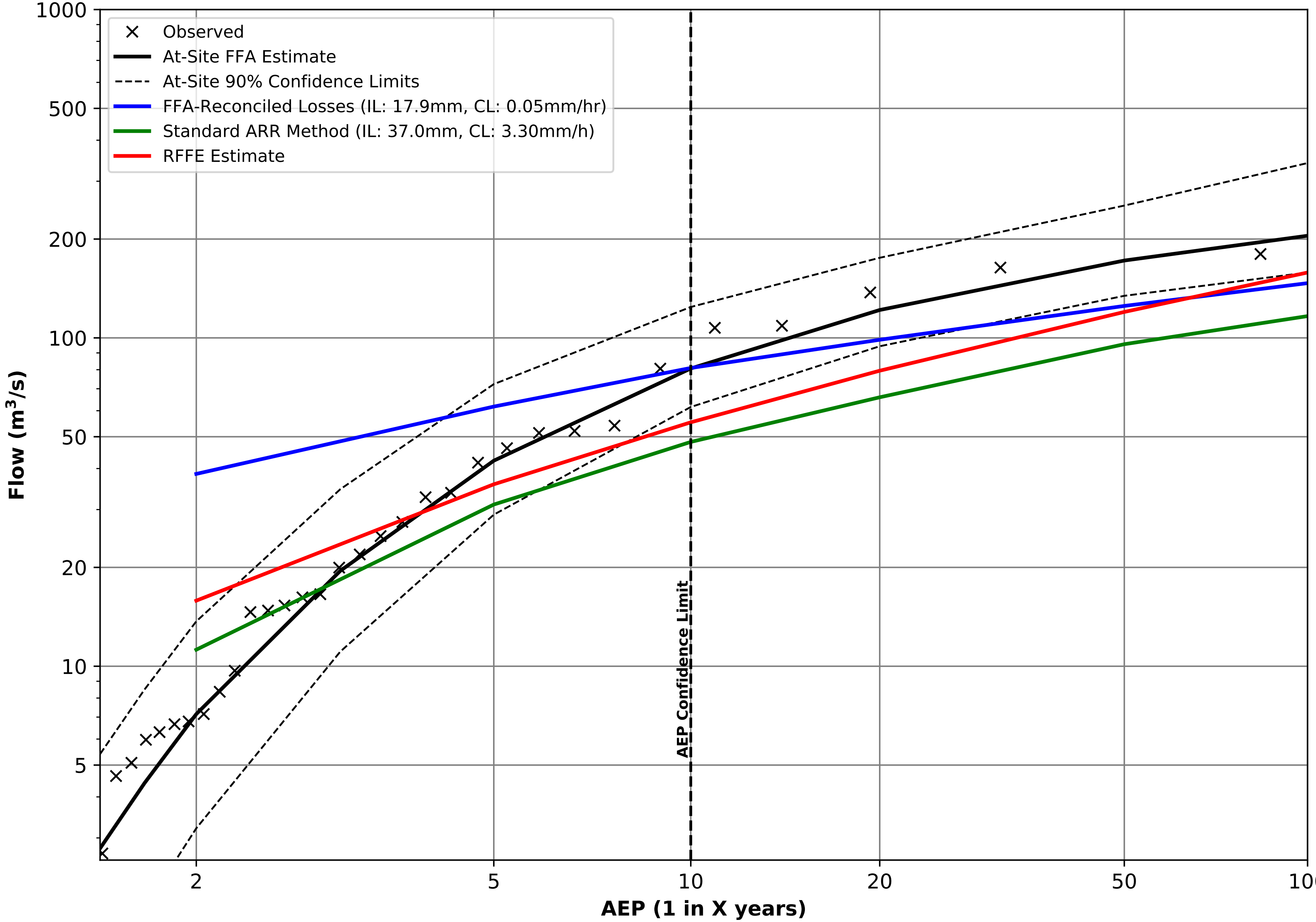
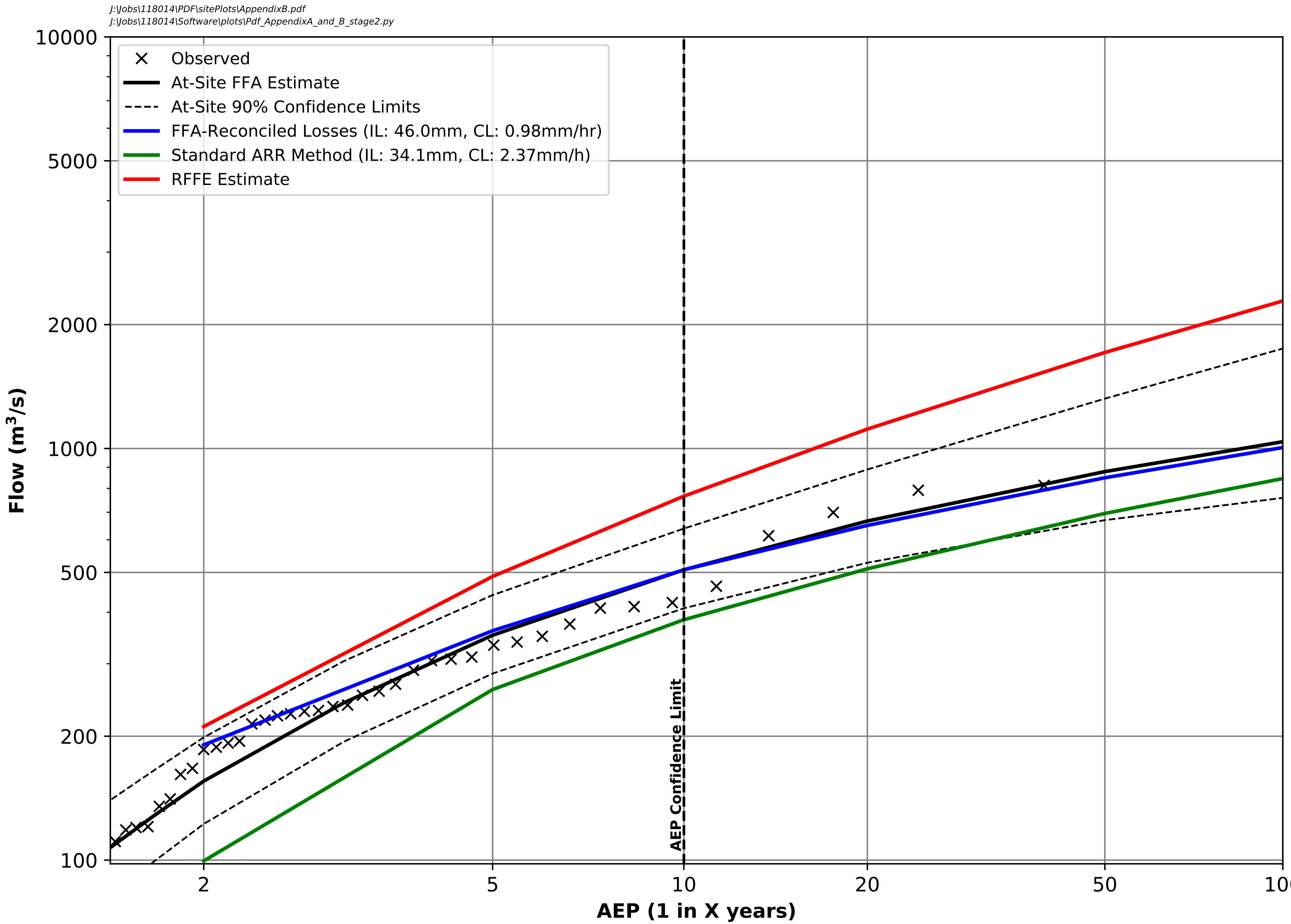


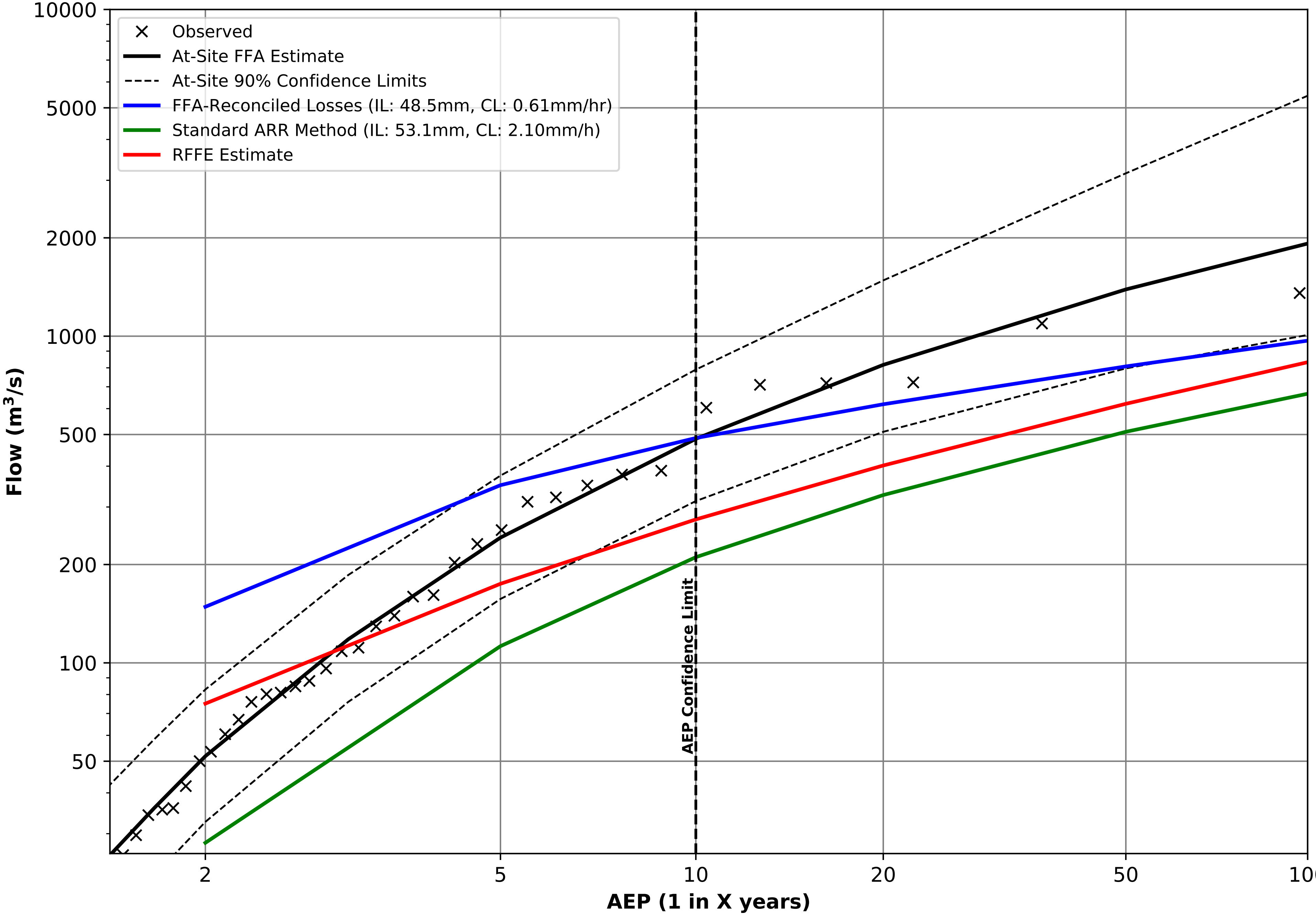
METHOD COMPARISON
POKOLBIN SITE 3 - 210068 [H13]

APPENDIX B89

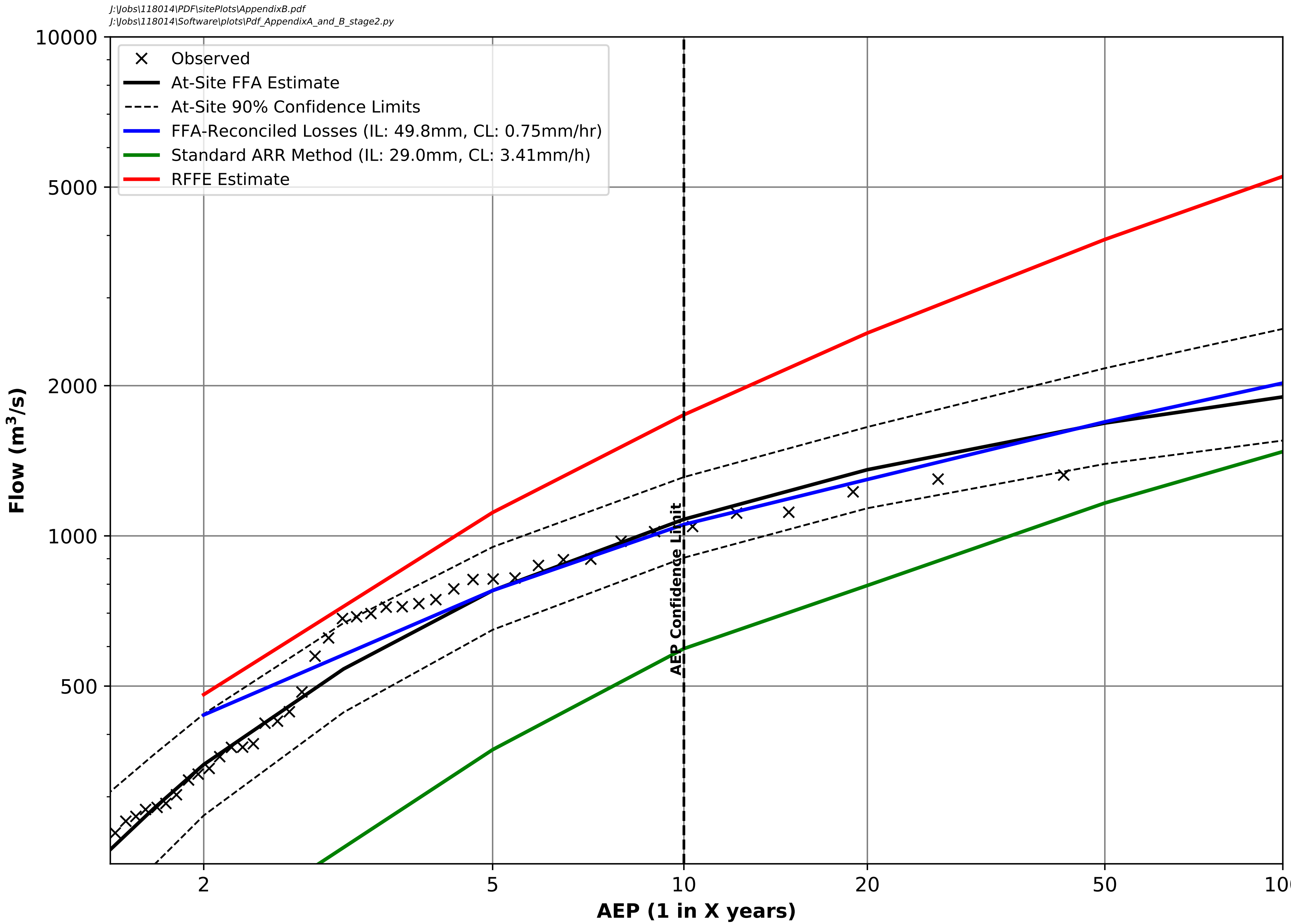


METHOD COMPARISON
MIDDLE FALBROOK(FAL DAM SI - 210044 [H14]

APPENDIX B90



METHOD COMPARISON
WYBONG - 210040 [H15]



METHOD COMPARISON

GOSTWYCK - 210079 [H16]

APPENDIX B92

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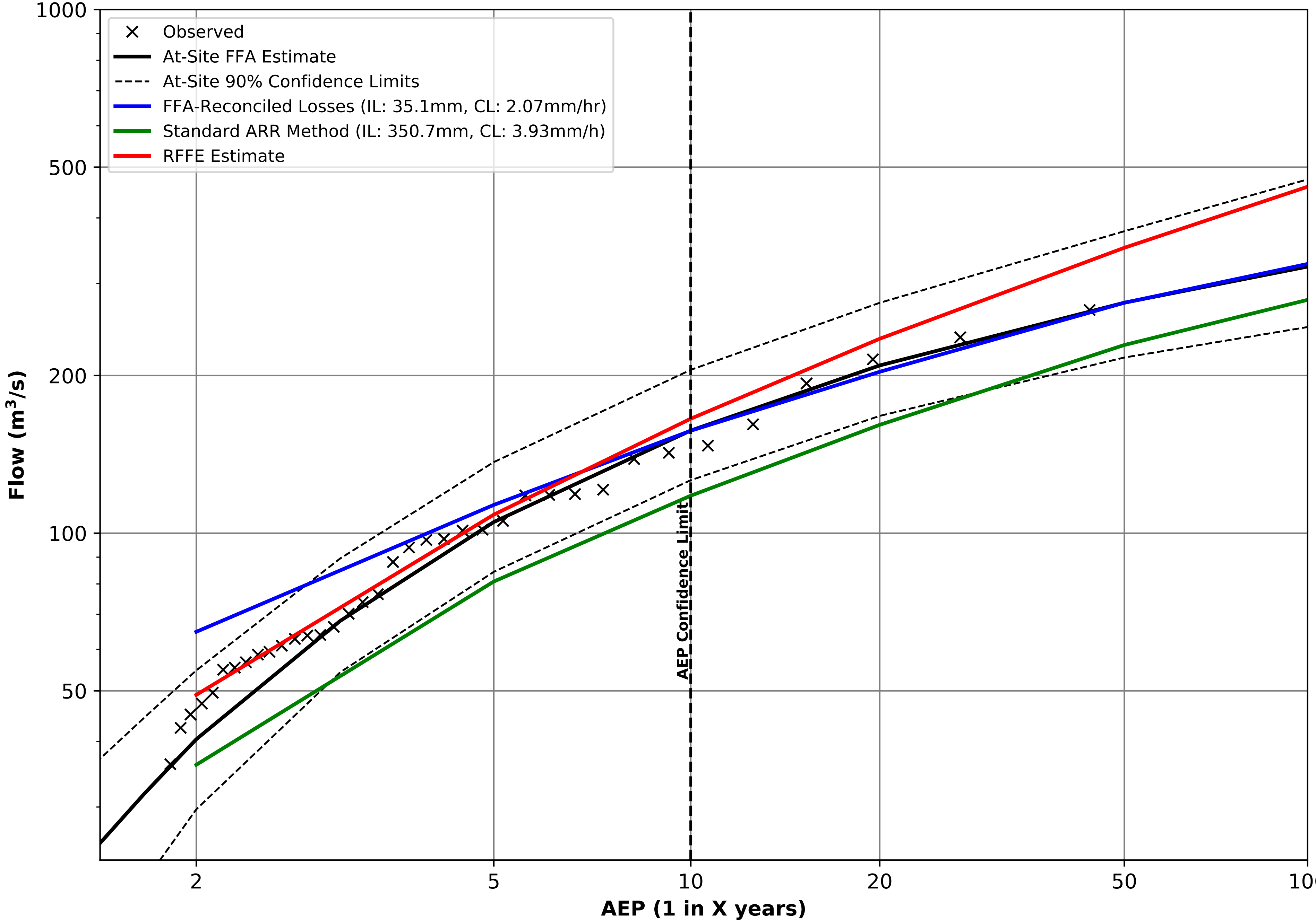

METHOD COMPARISON
BARRY - 208009 [H17]

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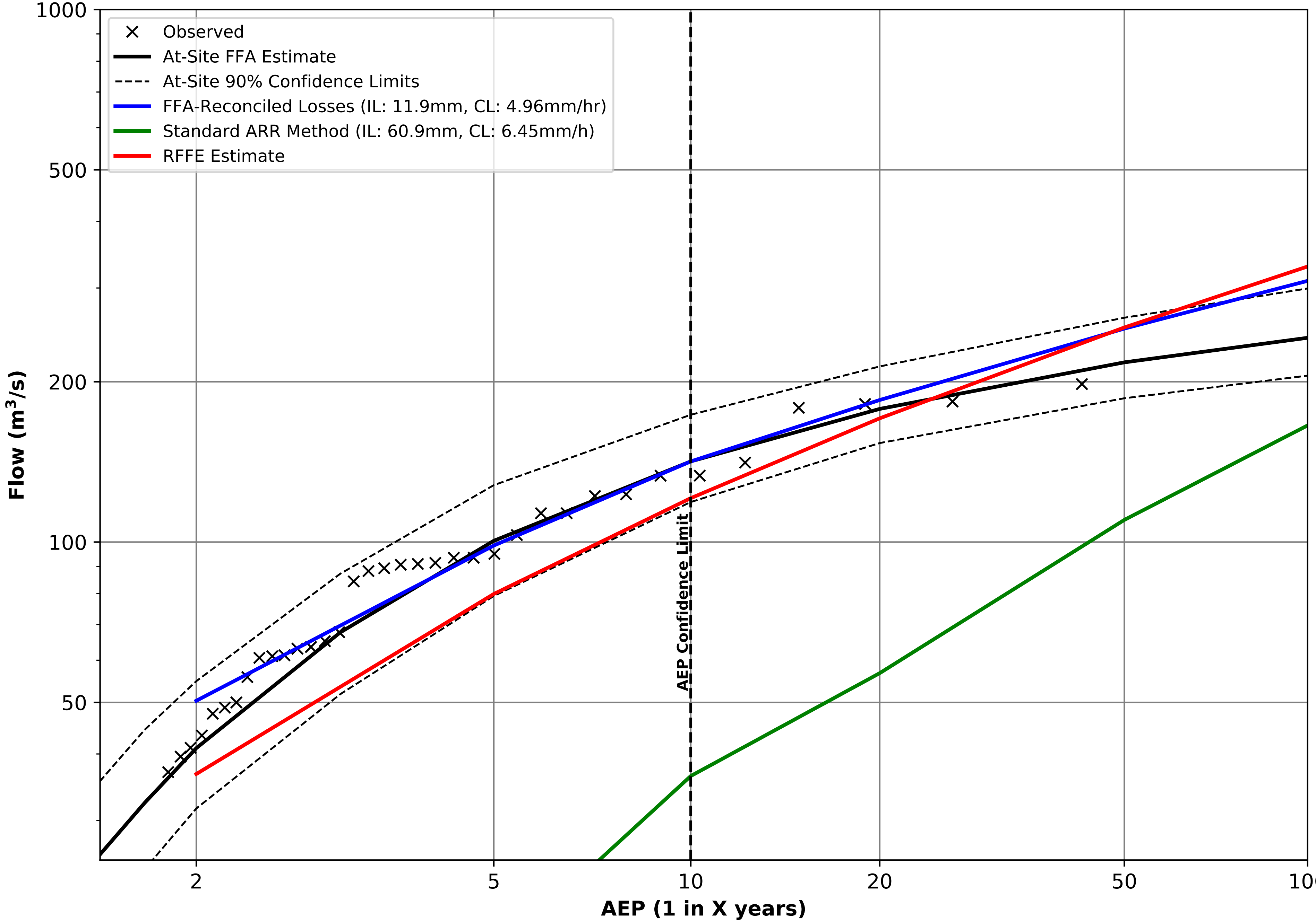

METHOD COMPARISON
NOWENDOC - 208007 [H18]

APPENDIX B94

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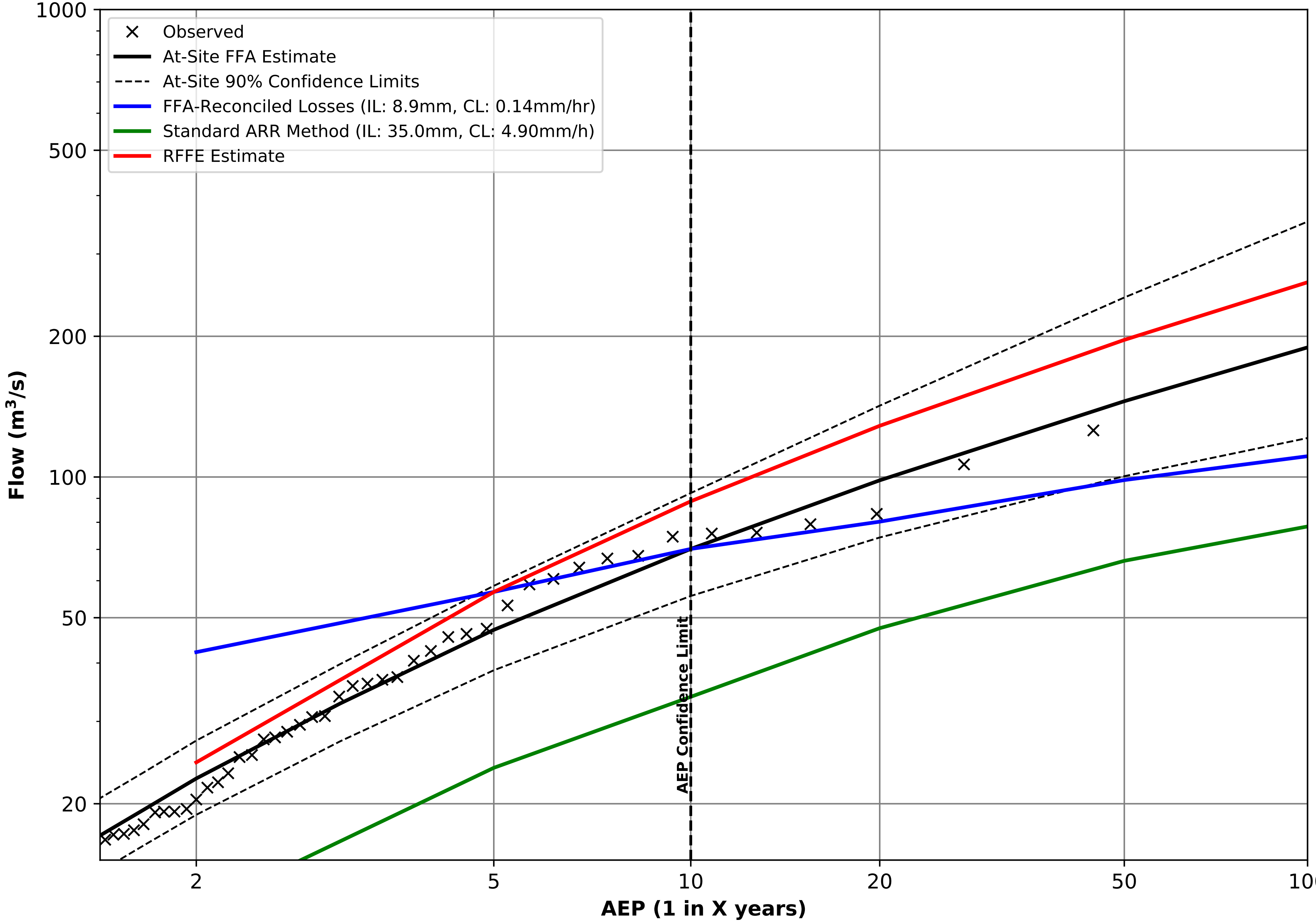
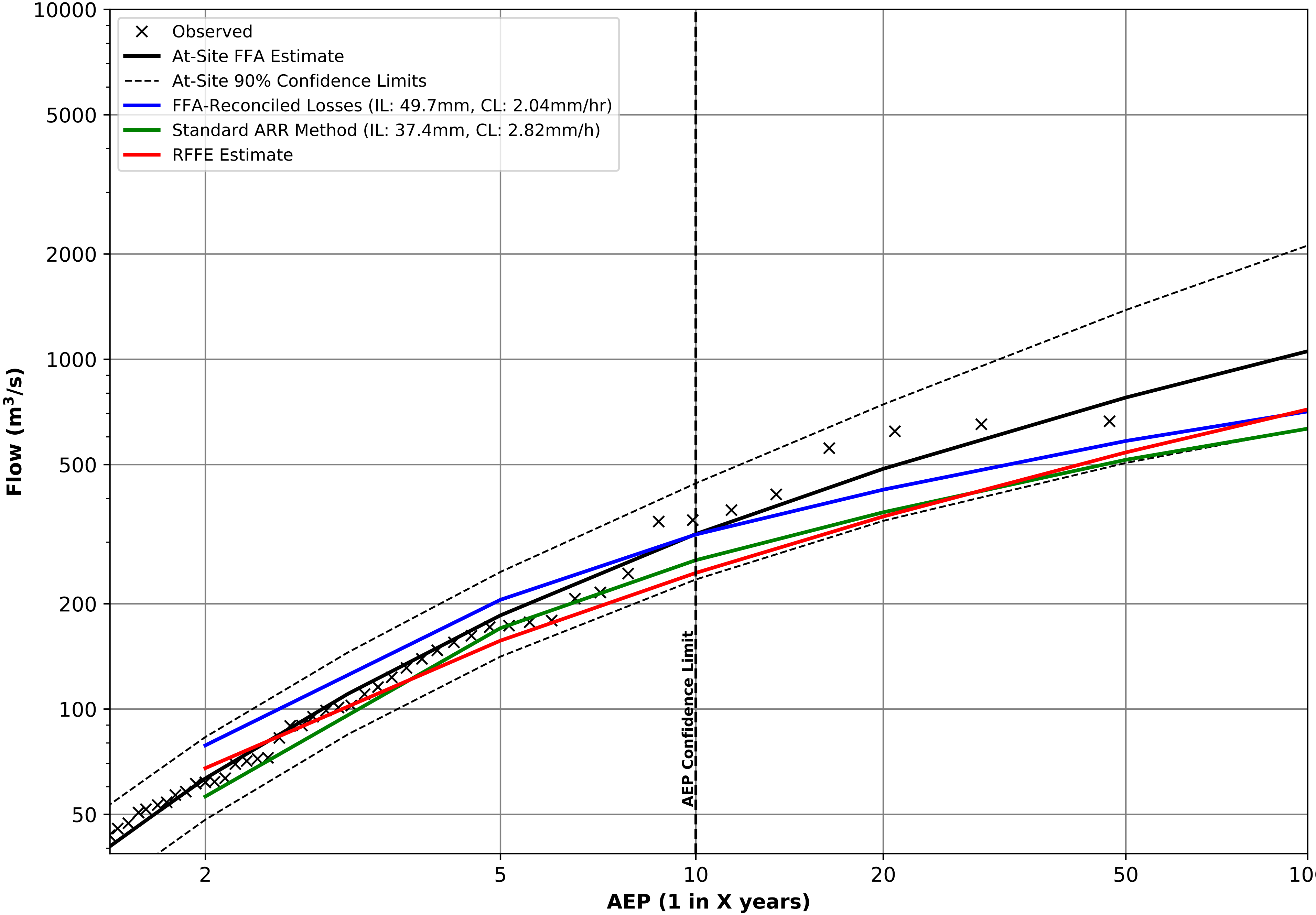
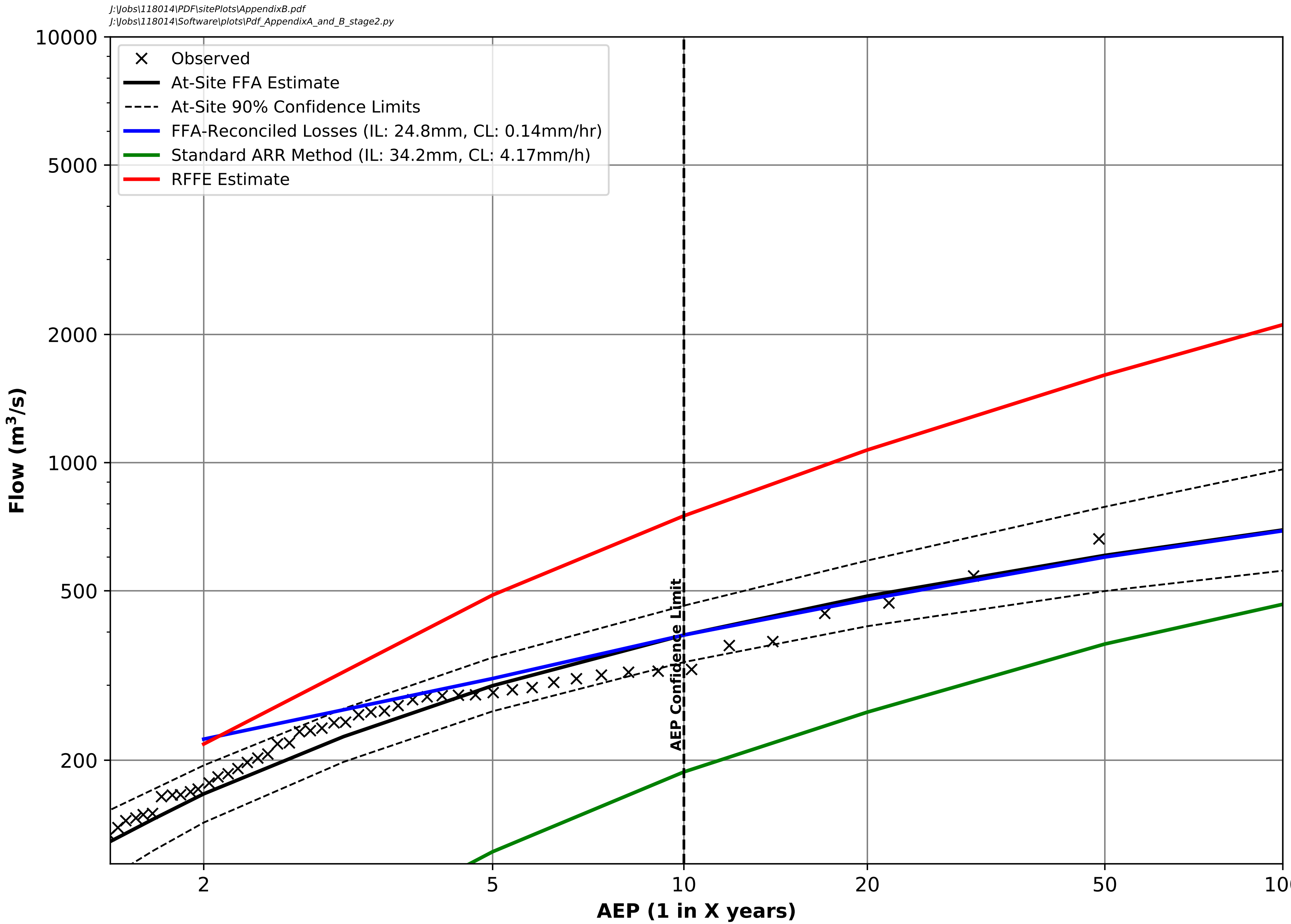


METHOD COMPARISON
BOBS CROSSING - 208001 [H19]

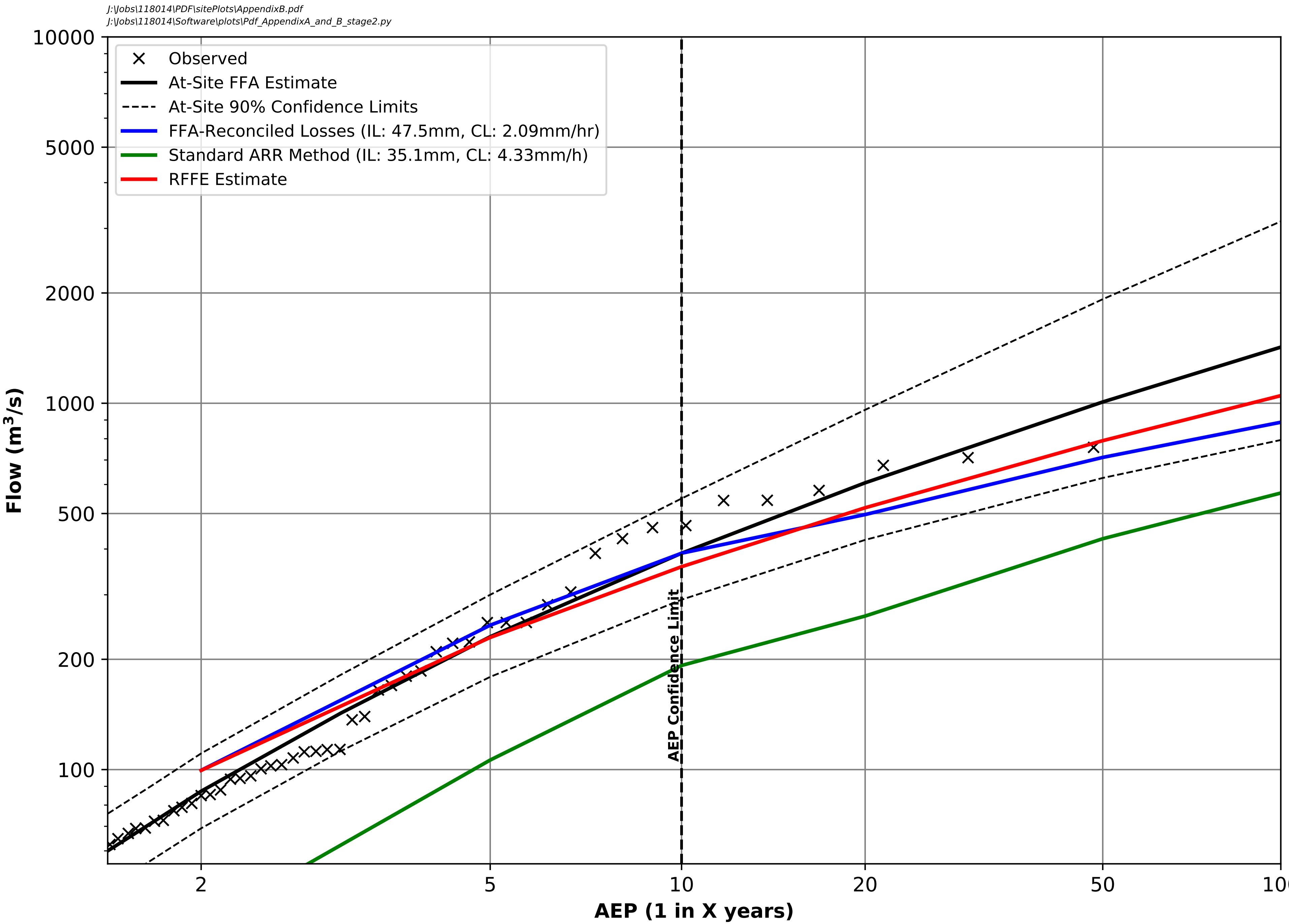


ROUCHEL BROOK (THE VALE) - 210014 [H20]
METHOD COMPARISON



METHOD COMPARISON
HALTON - 210022 [H21]

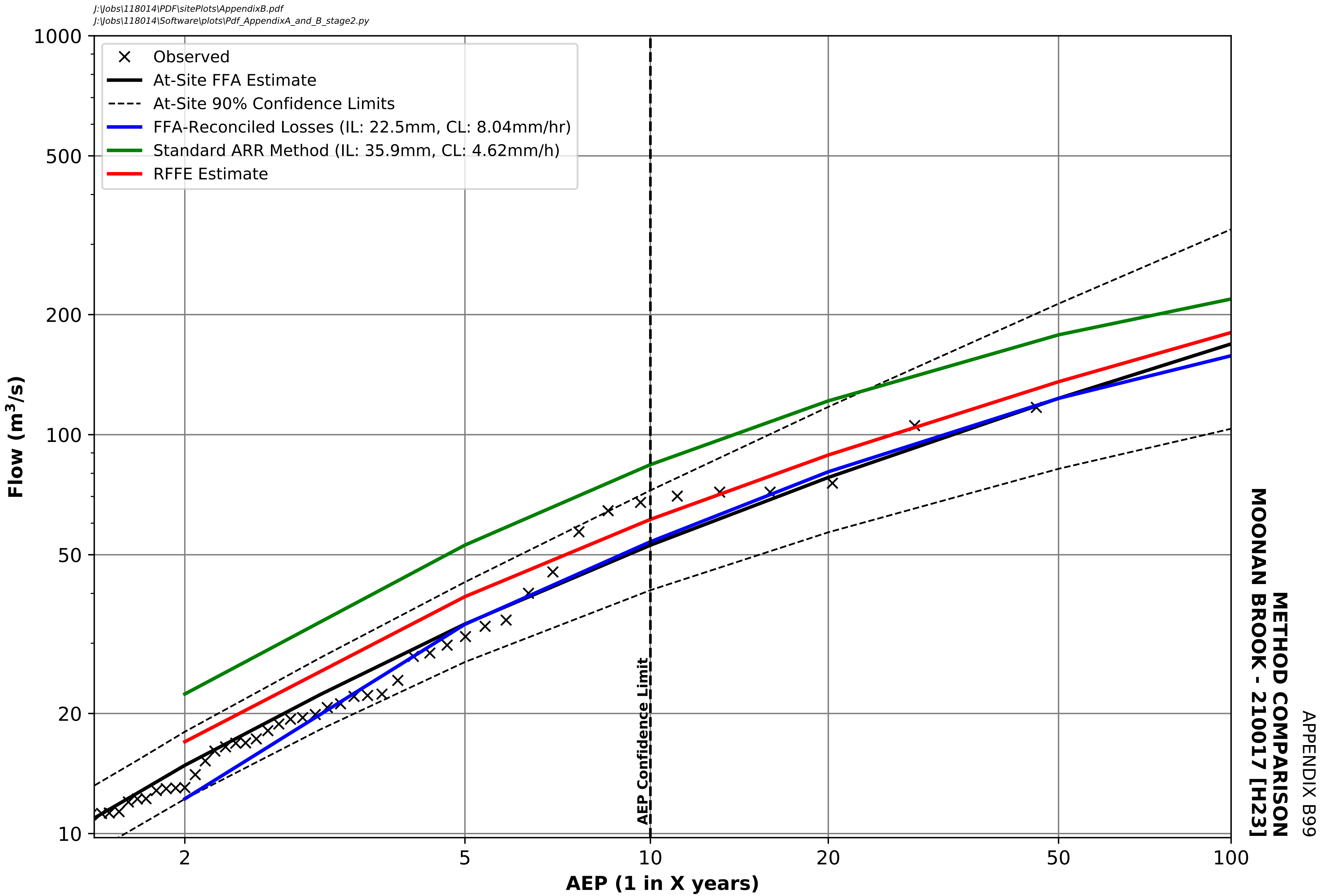
APPENDIX B97



METHOD COMPARISON

MOONAM DAM SITE - 210018 [H22]

APPENDIX B98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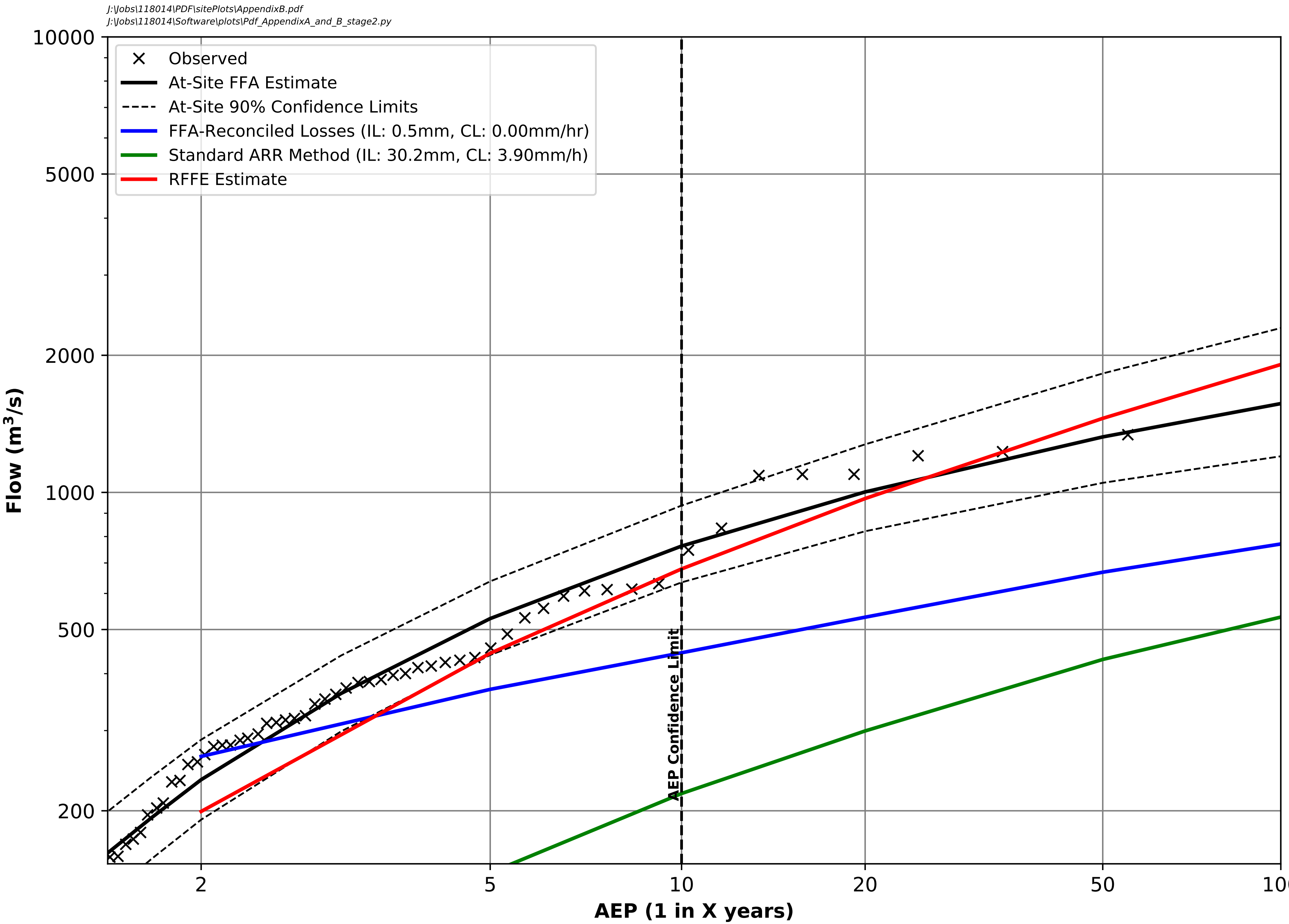
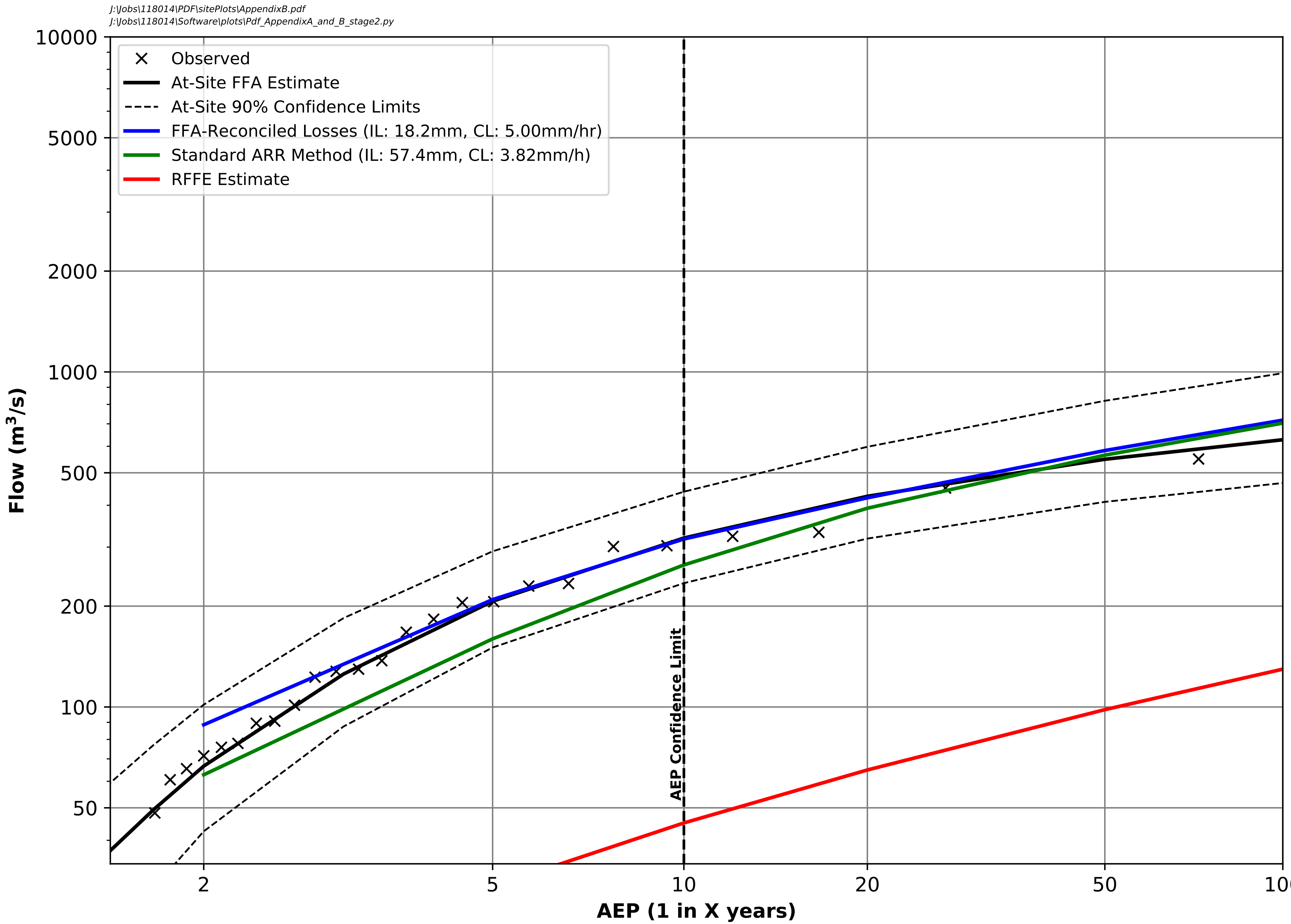
J:\Jobs\118014\Software\plots\Pdf_AppendixA_and_B_stage2.py
Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 22.5mm, CL: 8.04mm/hr)
Standard ARR Method (IL: 35.9mm, CL: 4.62mm/h)
RFFE Estimate
AEP Confidence Limit
Flow (m³/s)
AEP (1 in X years)
1000
500
200
100
50
20
10
2
5
10
20
50
100
METHOD COMPARISON
MOONAN BROOK - 210017 [H23]
APPENDIX B99



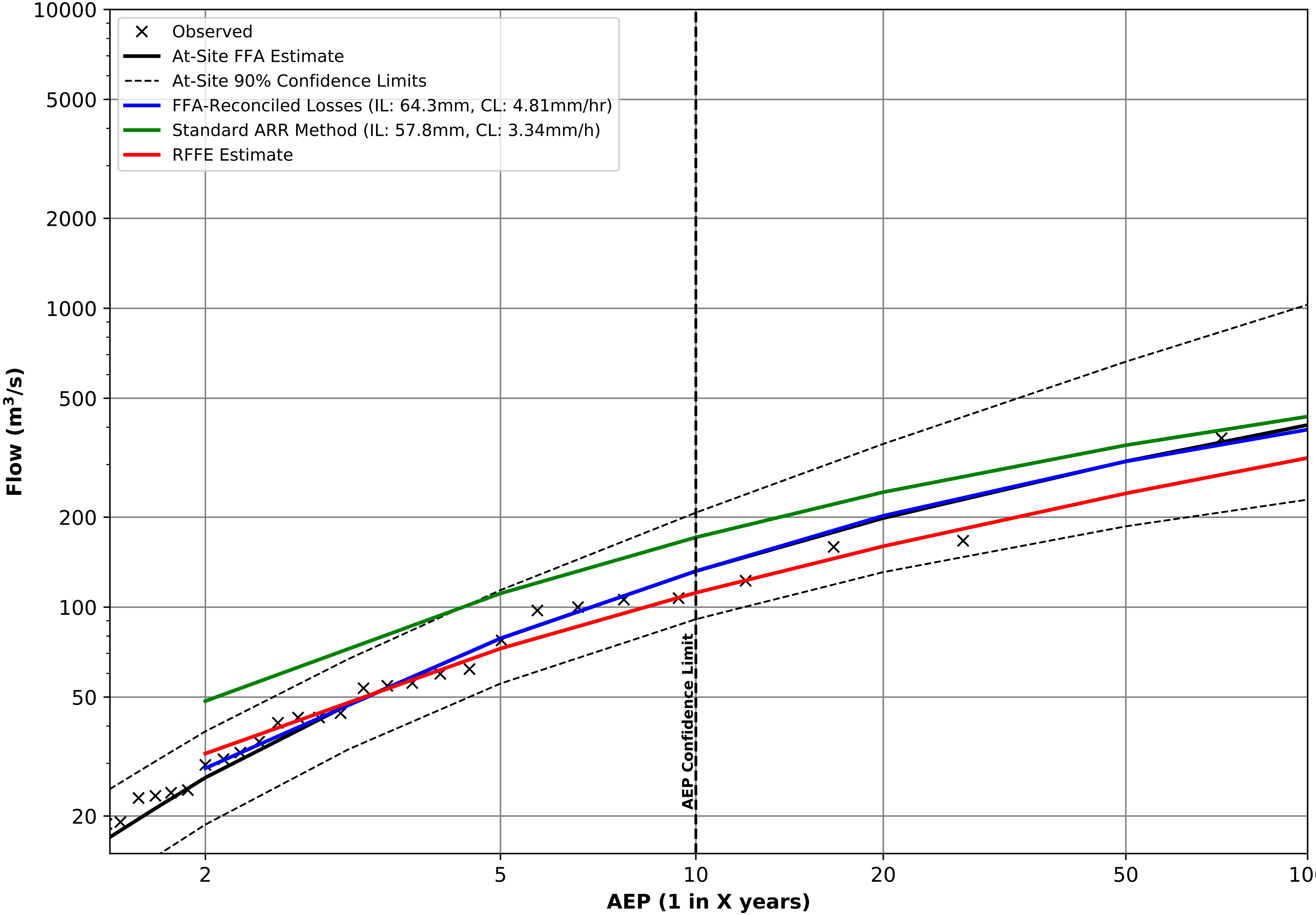
METHOD COMPARISON
TILLEGRA - 210011 [H24]

APPENDIX B100



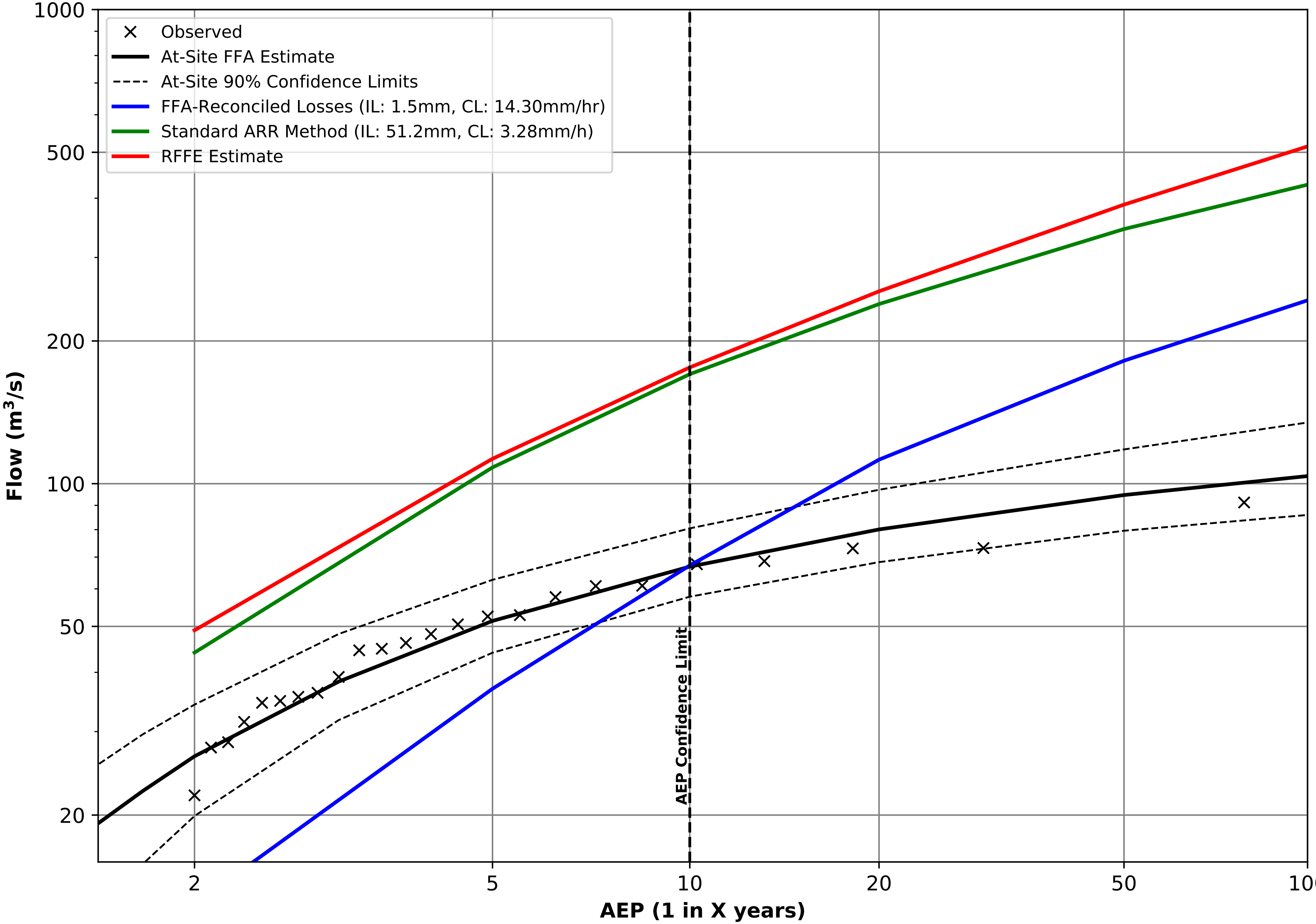
METHOD COMPARISON
YARRAMALONG - 211014 [H25]

APPENDIX B101



METHOD COMPARISON
U/S WEIR - 211013 [H26]

APPENDIX B102



METHOD COMPARISON
U/S WYONG R (DURREN LA) - 211010 [H27]

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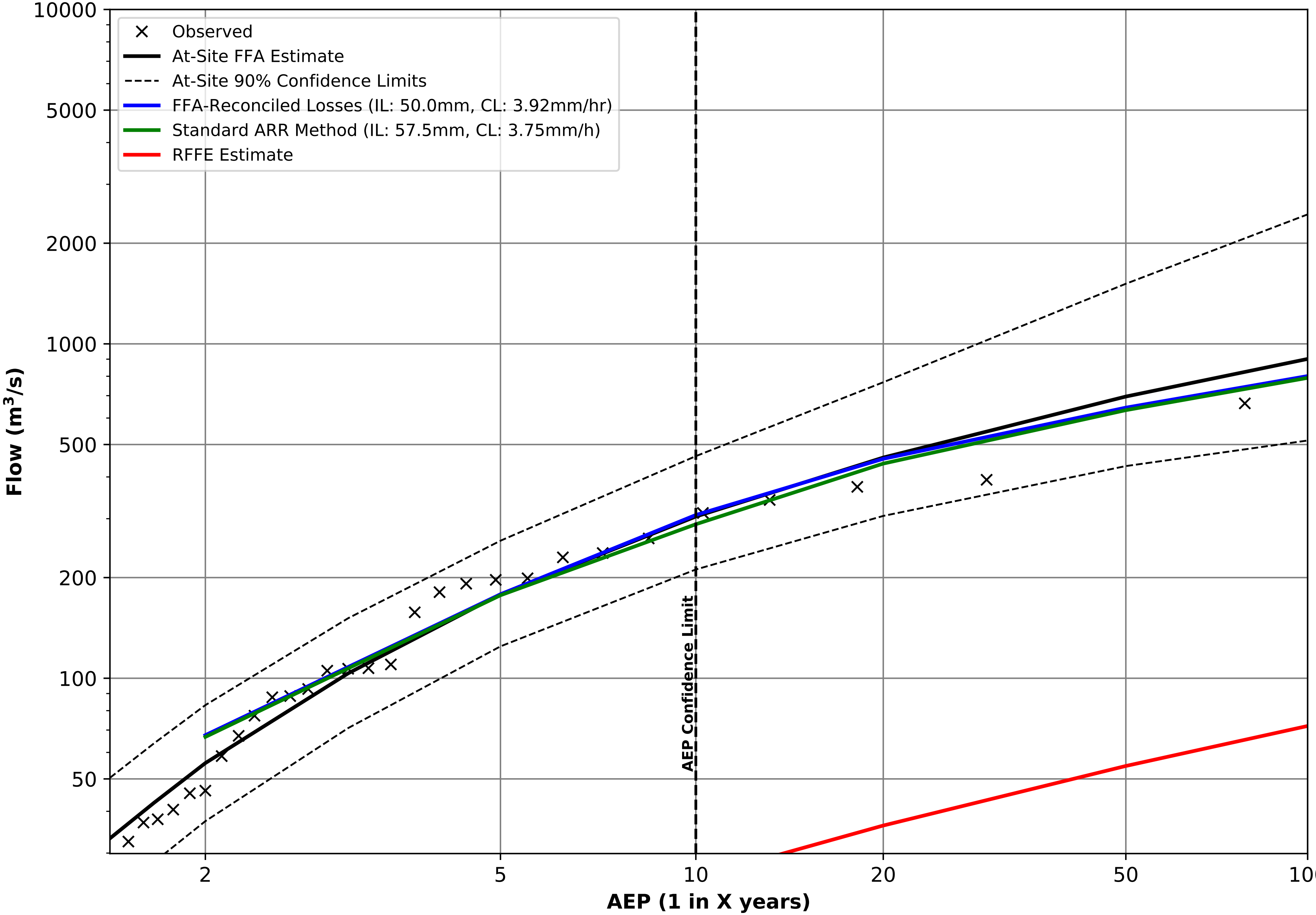
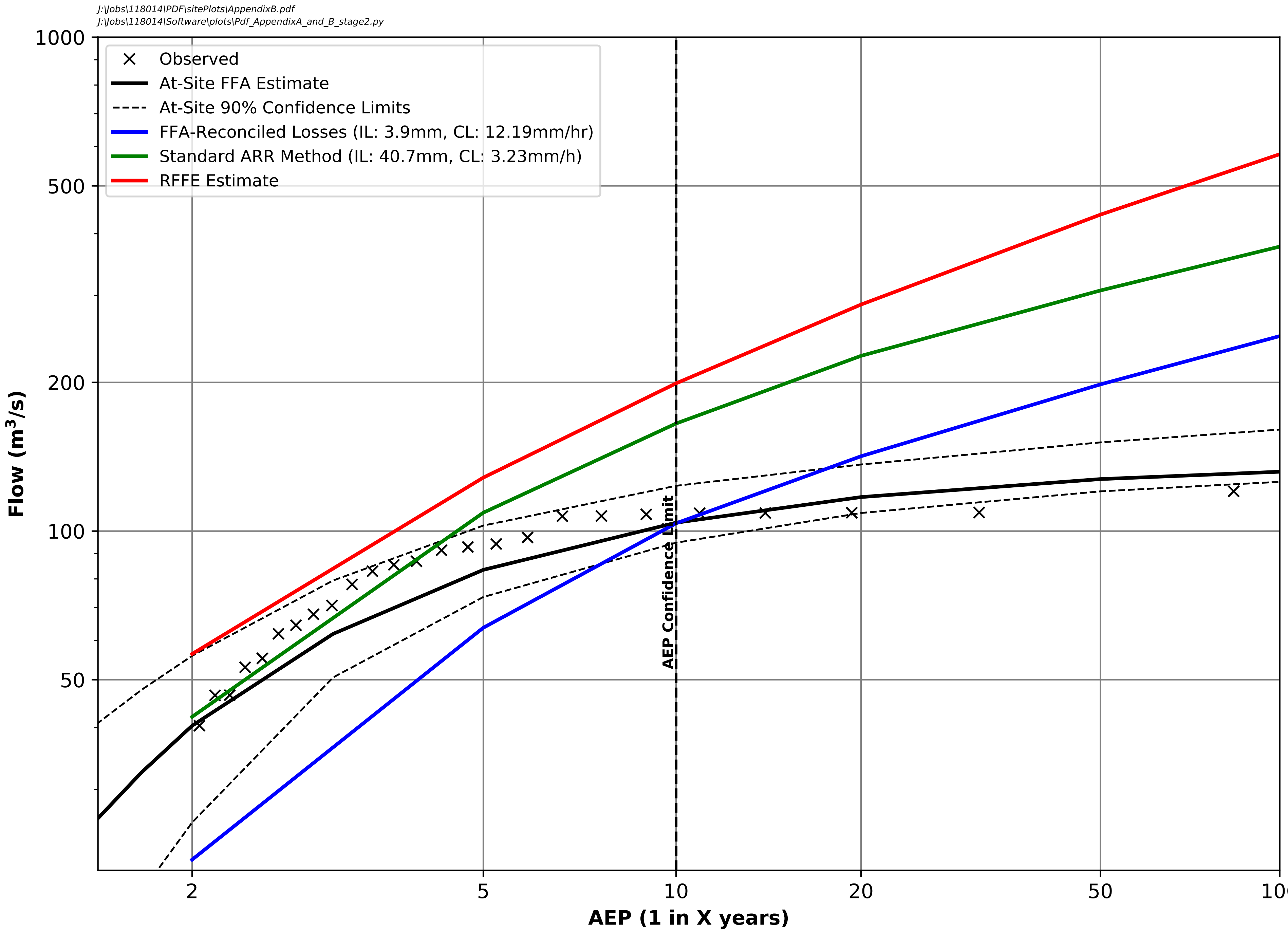
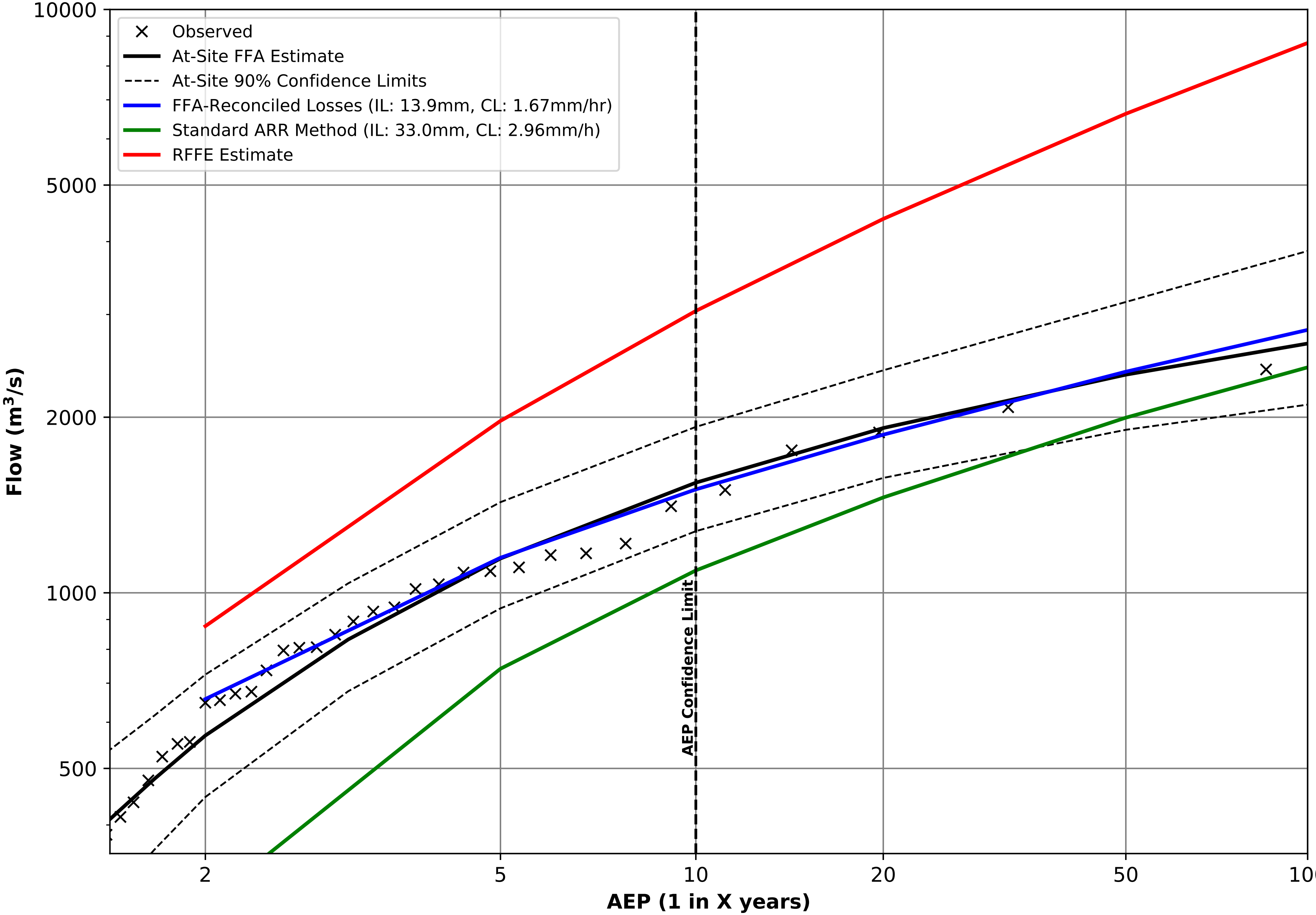


METHOD COMPARISON
GRACEMERE - 211009 [H28]



METHOD COMPARISON
AVONDALE - 211008 [H29]

APPENDIX B105



METHOD COMPARISON
BOORAL - 209003 [H30]

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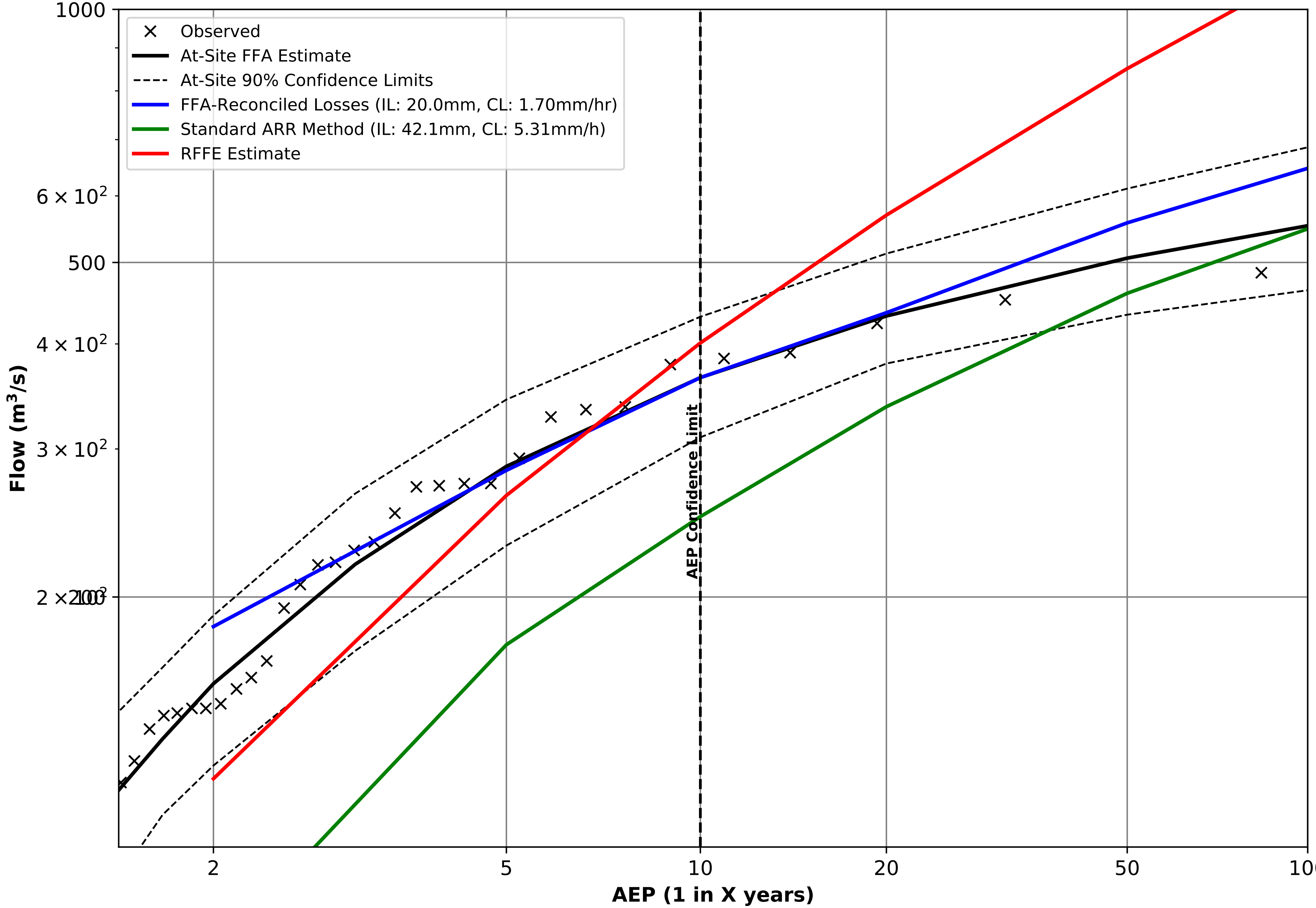
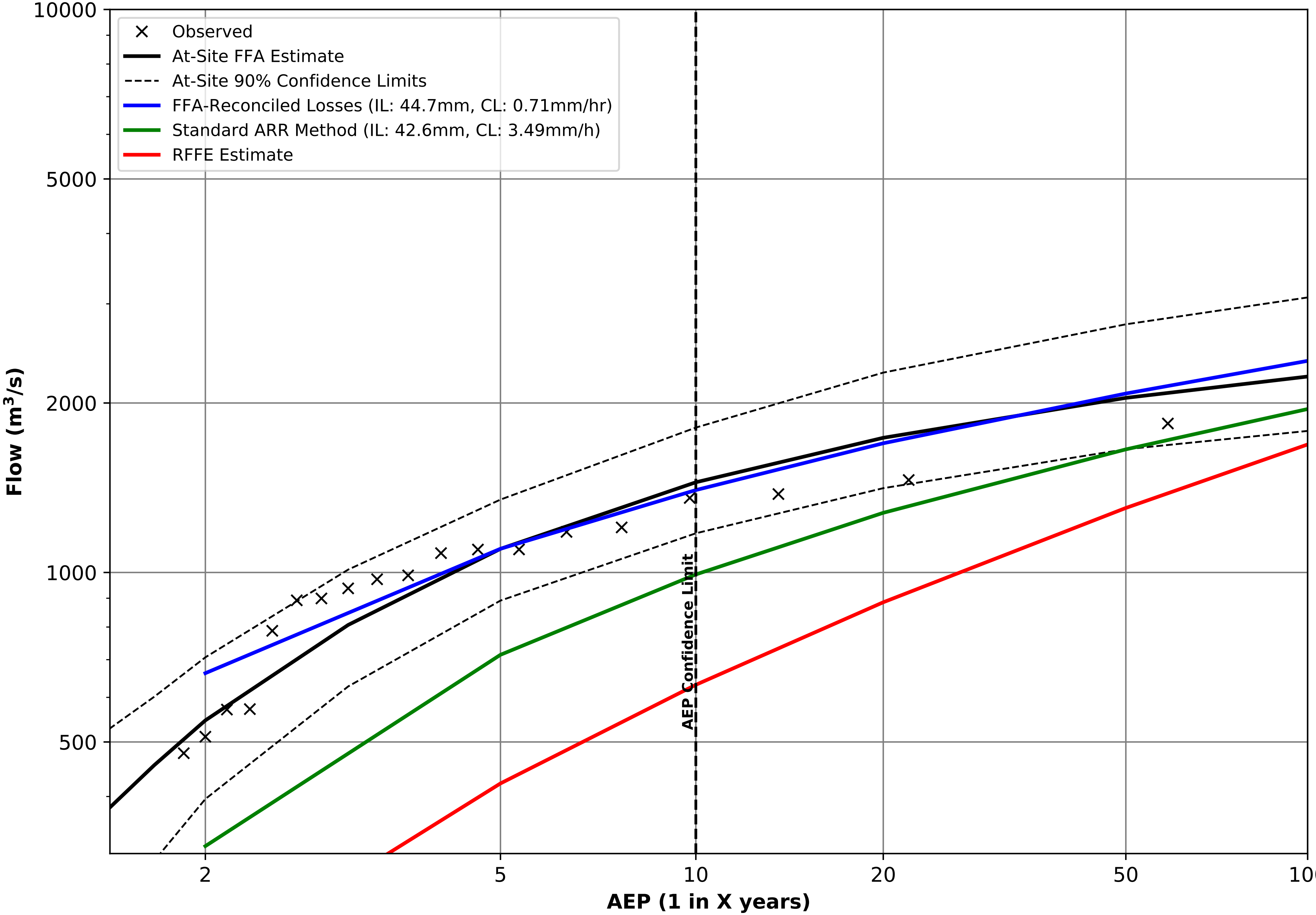
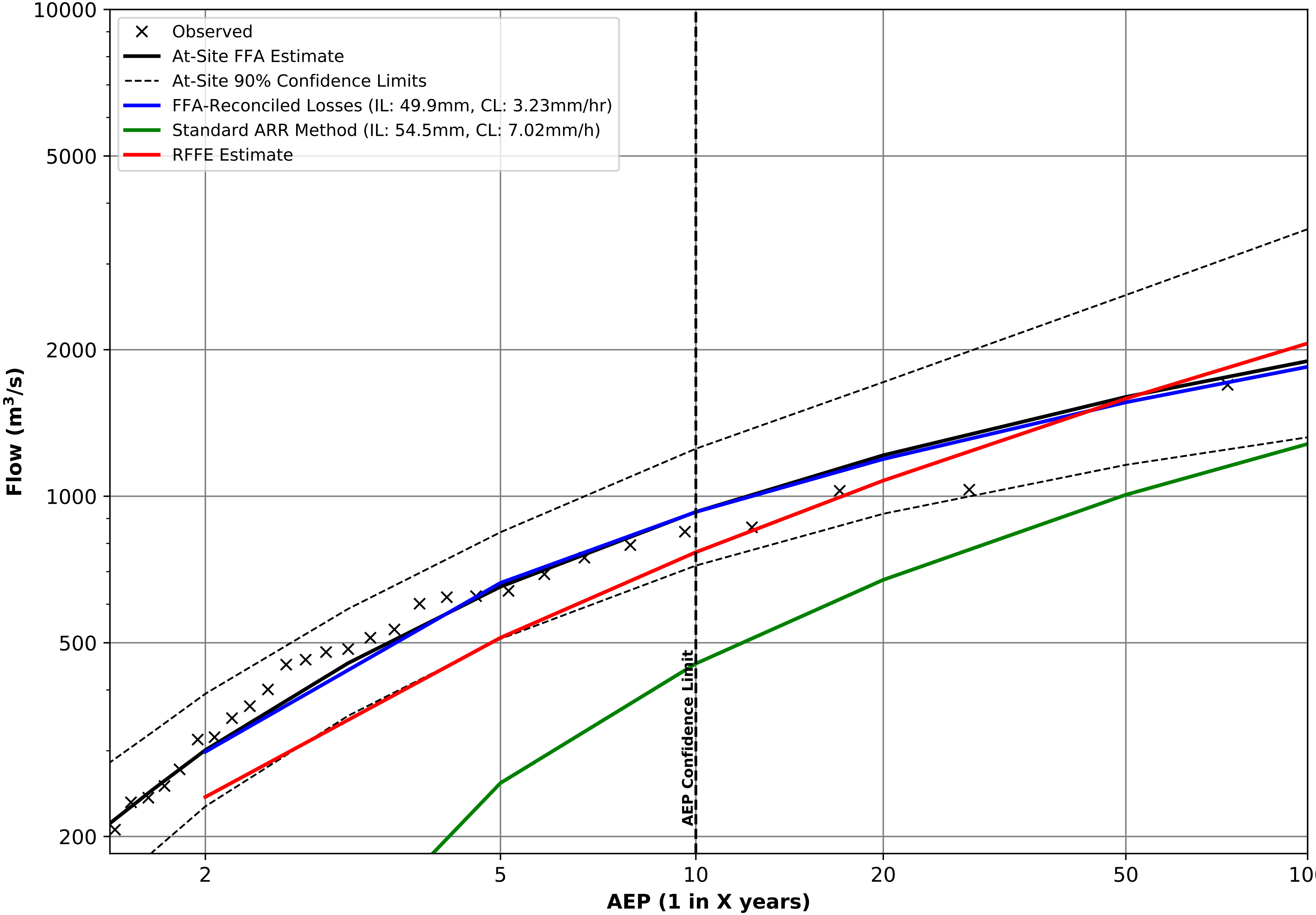


METHOD COMPARISON
LANDSDOWNE - 208015 [H31]

APPENDIX B107



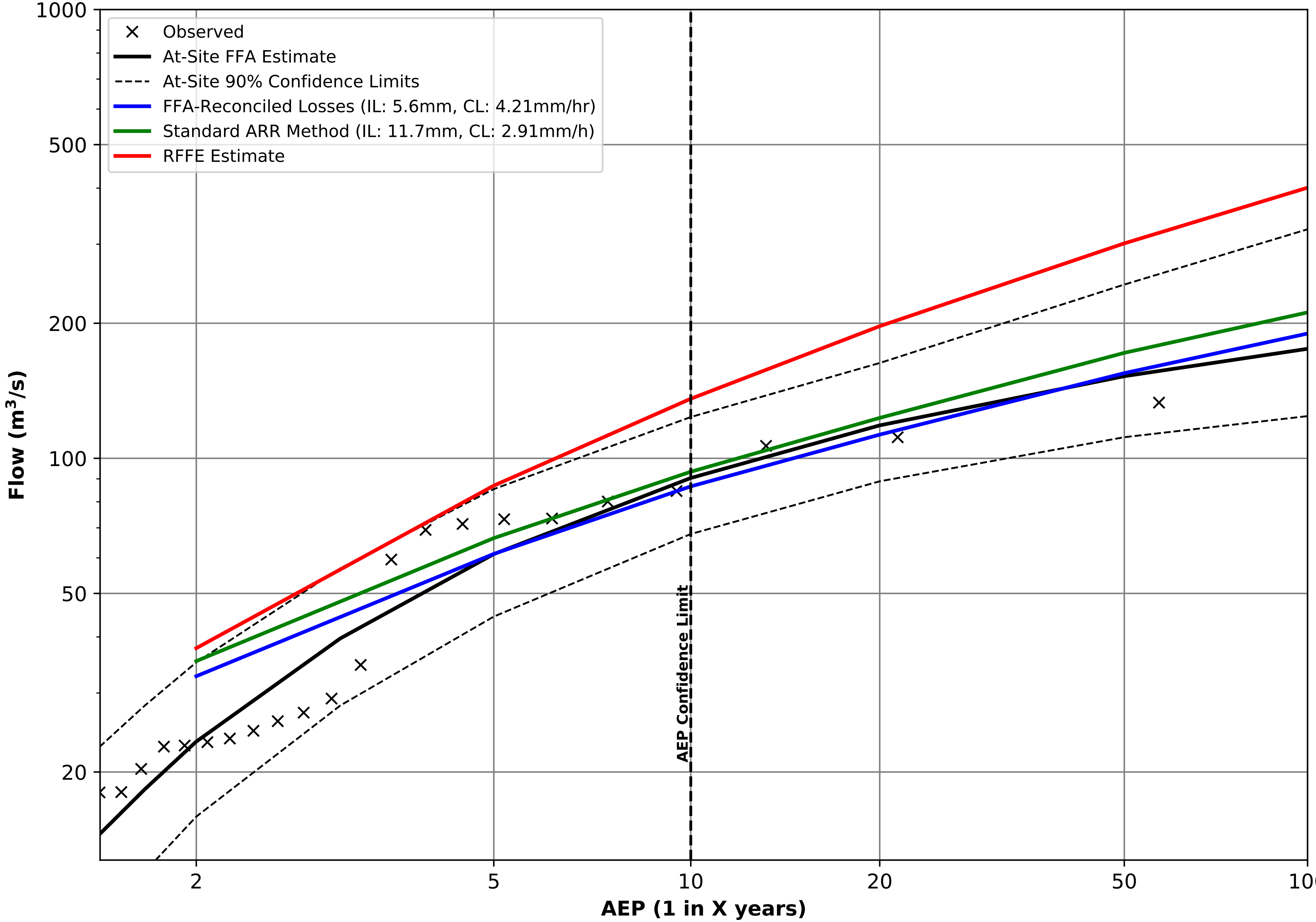
METHOD COMPARISON
AVENEL - 207014 [H32]



D/S BUNNOO R JUNCTION - 207013 [H33]

METHOD COMPARISON

APPENDIX B109



METHOD COMPARISON
ABERMALA - 206034 [I1]

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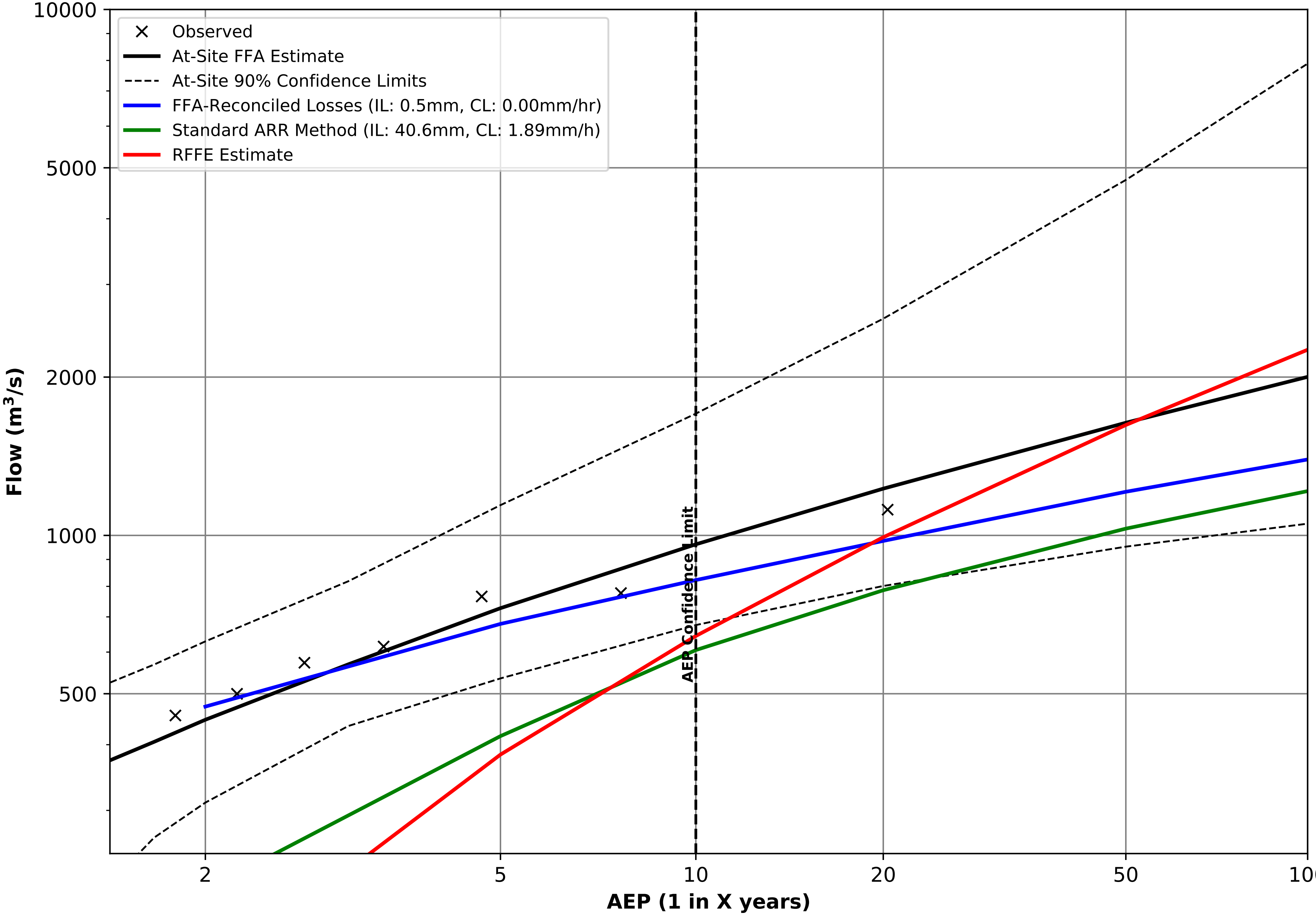
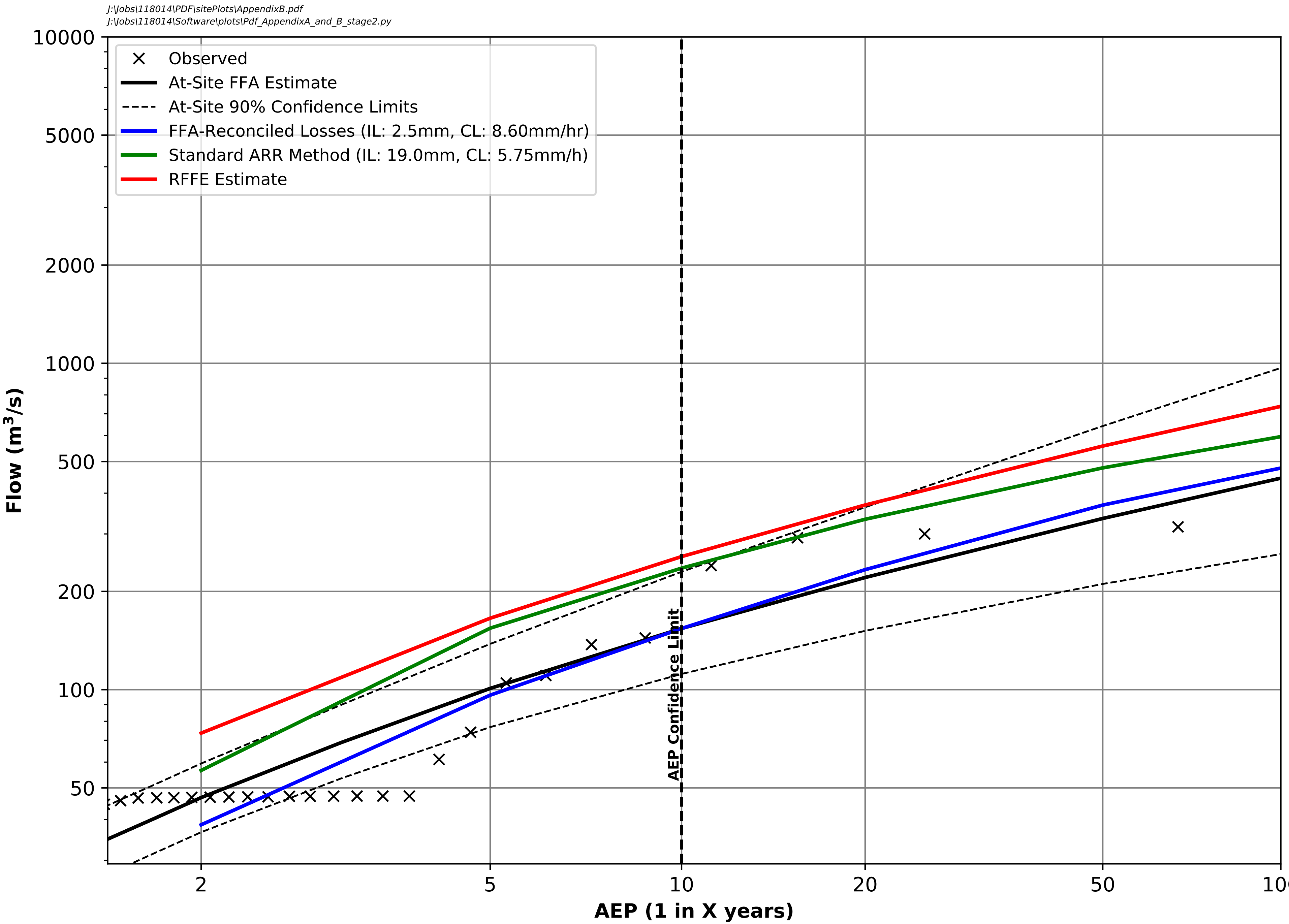
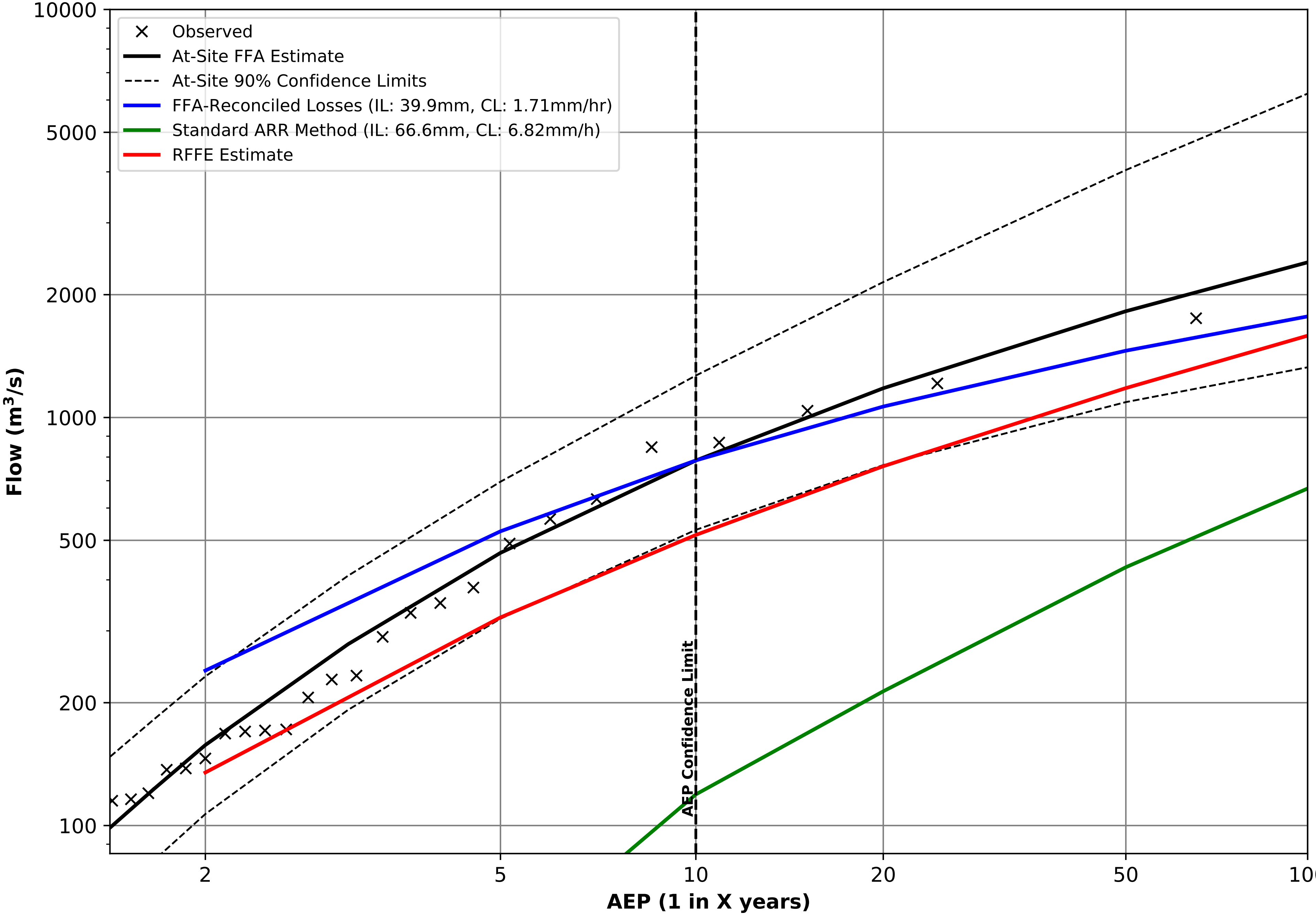


METHOD COMPARISON
FINE FLOWER - 204067 [I2]

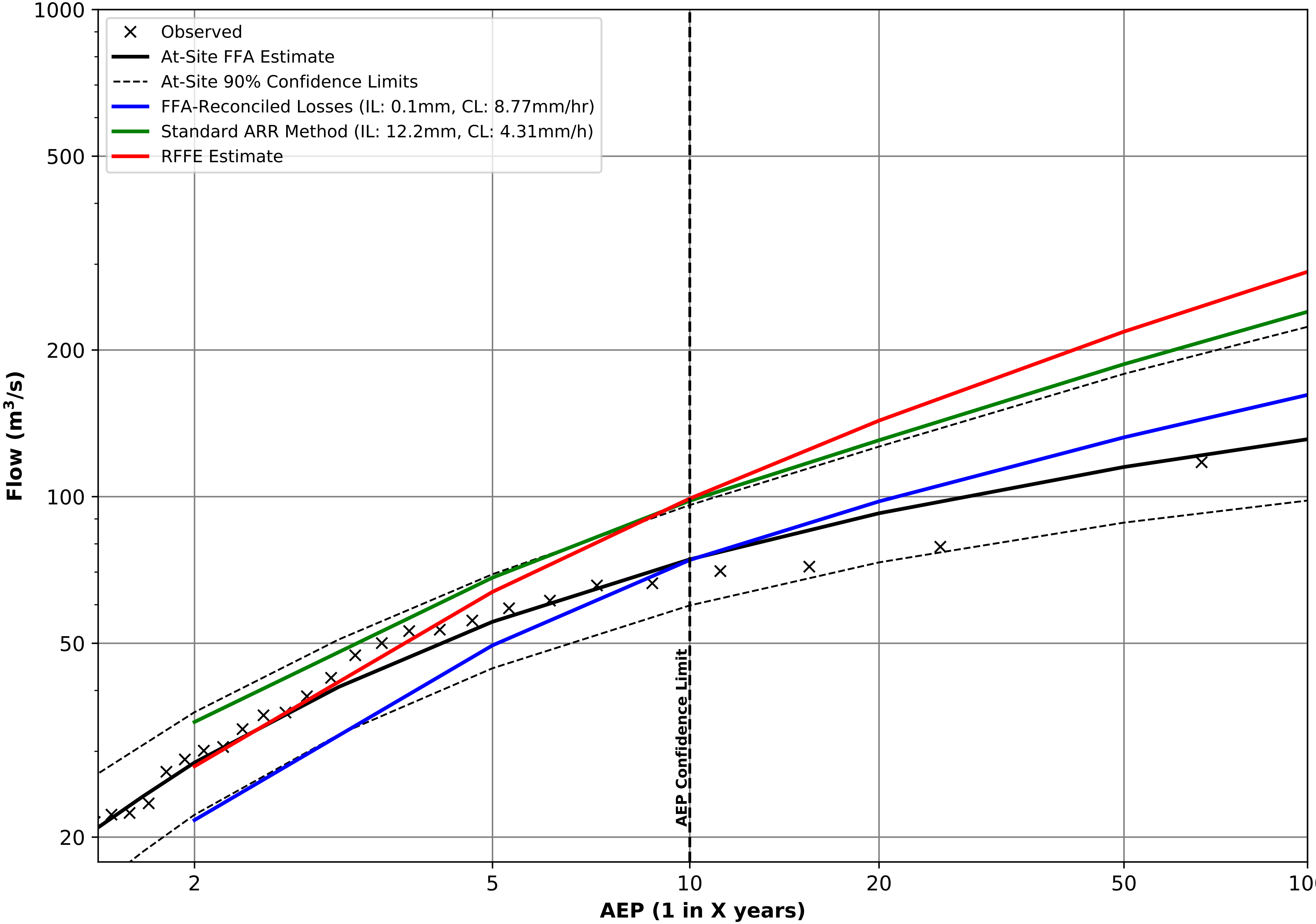
APPENDIX B111



METHOD COMPARISON
JEOGLA - 206001 [I3]



METHOD COMPARISON
BILLYRIMBA - 204033 [I4]



METHOD COMPARISON
ABERFOYLE - 204030 [I5]

APPENDIX B114

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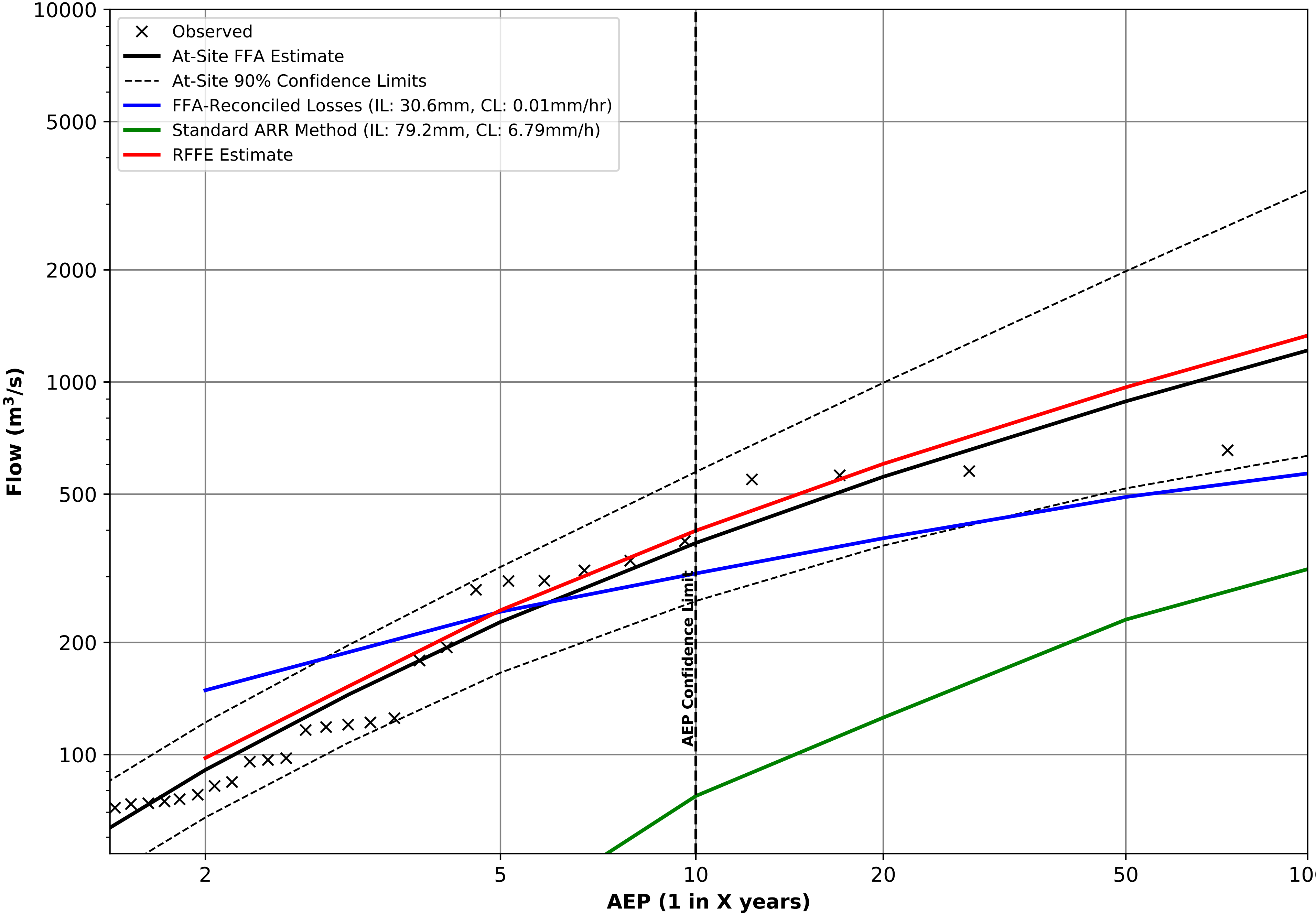

METHOD COMPARISON
GIBRALTAR RANGE - 204056 [I6]

APPENDIX B115

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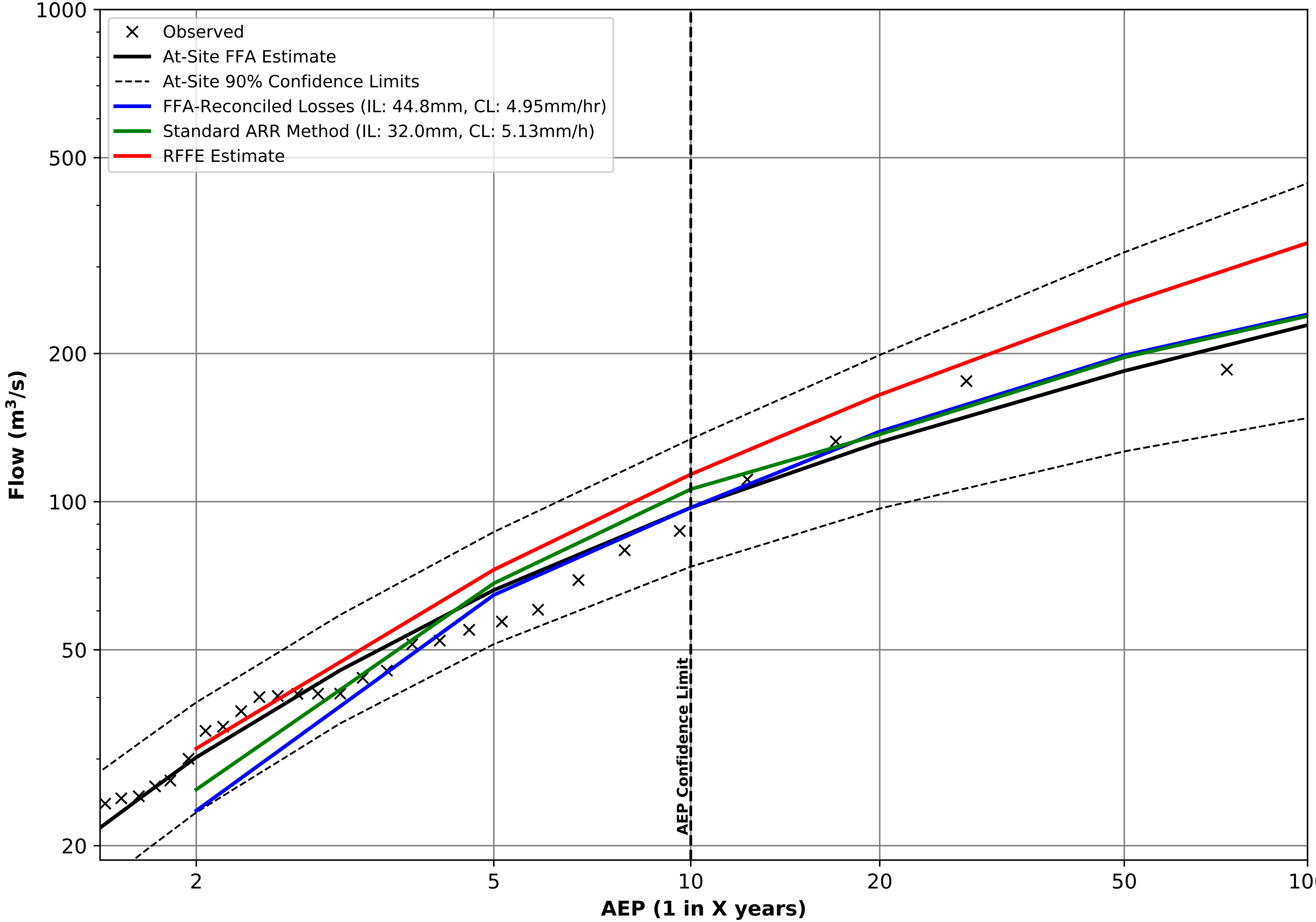
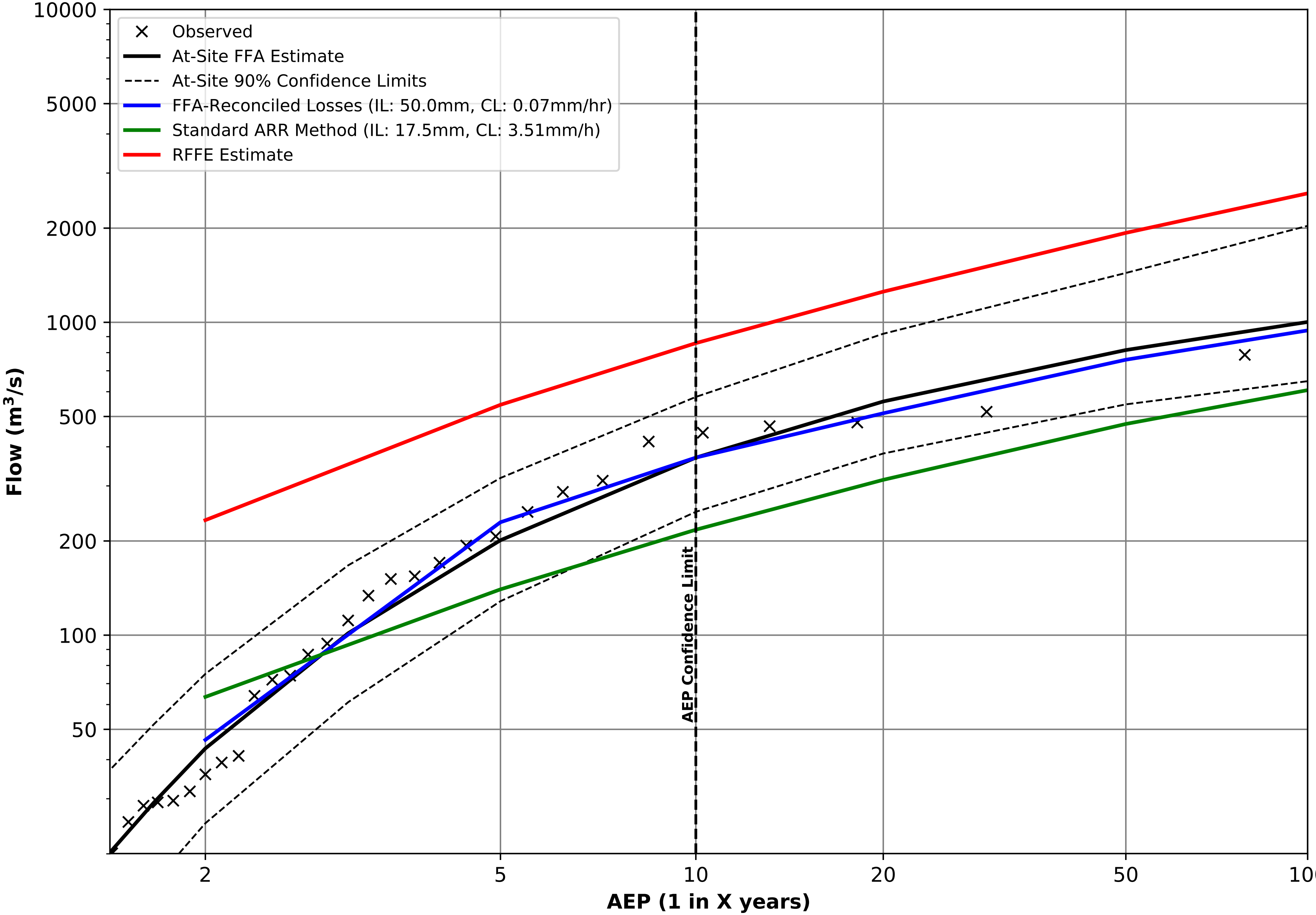


METHOD COMPARISON
EBOR - 204008 [17]

APPENDIX B116



METHOD COMPARISON

NEAR DANGAR FALLS - 206025 [I8]

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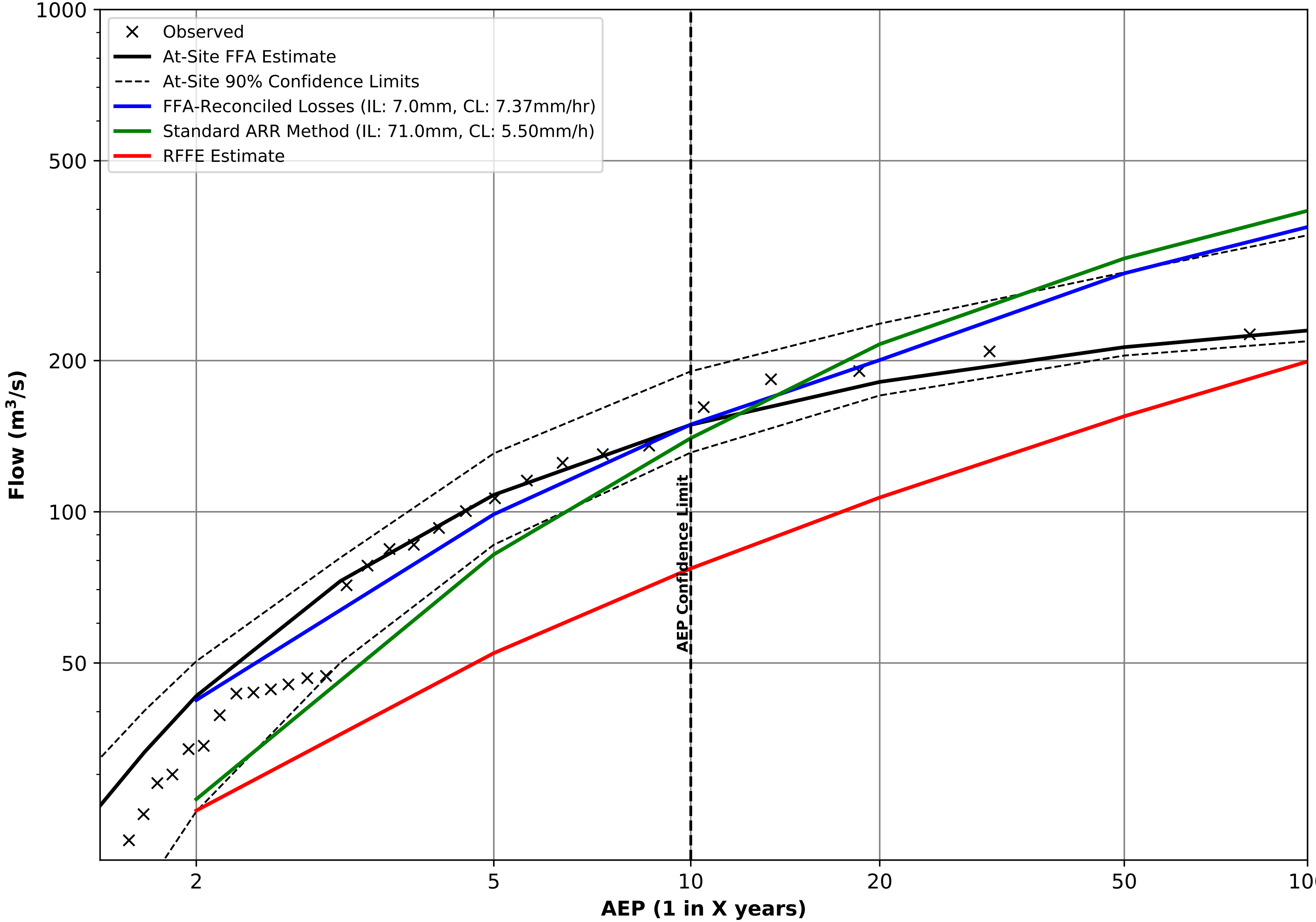
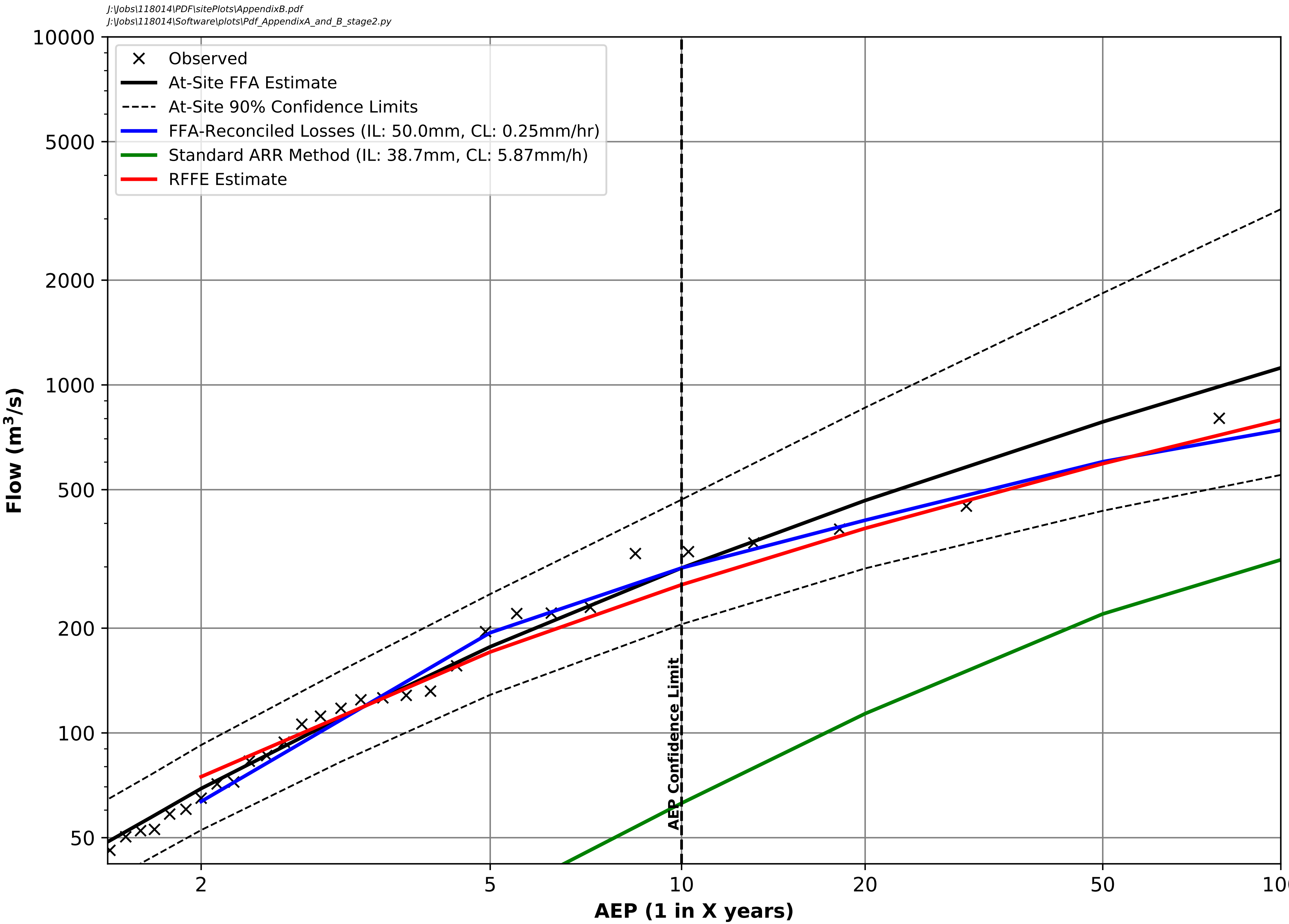


APPENDIX B118

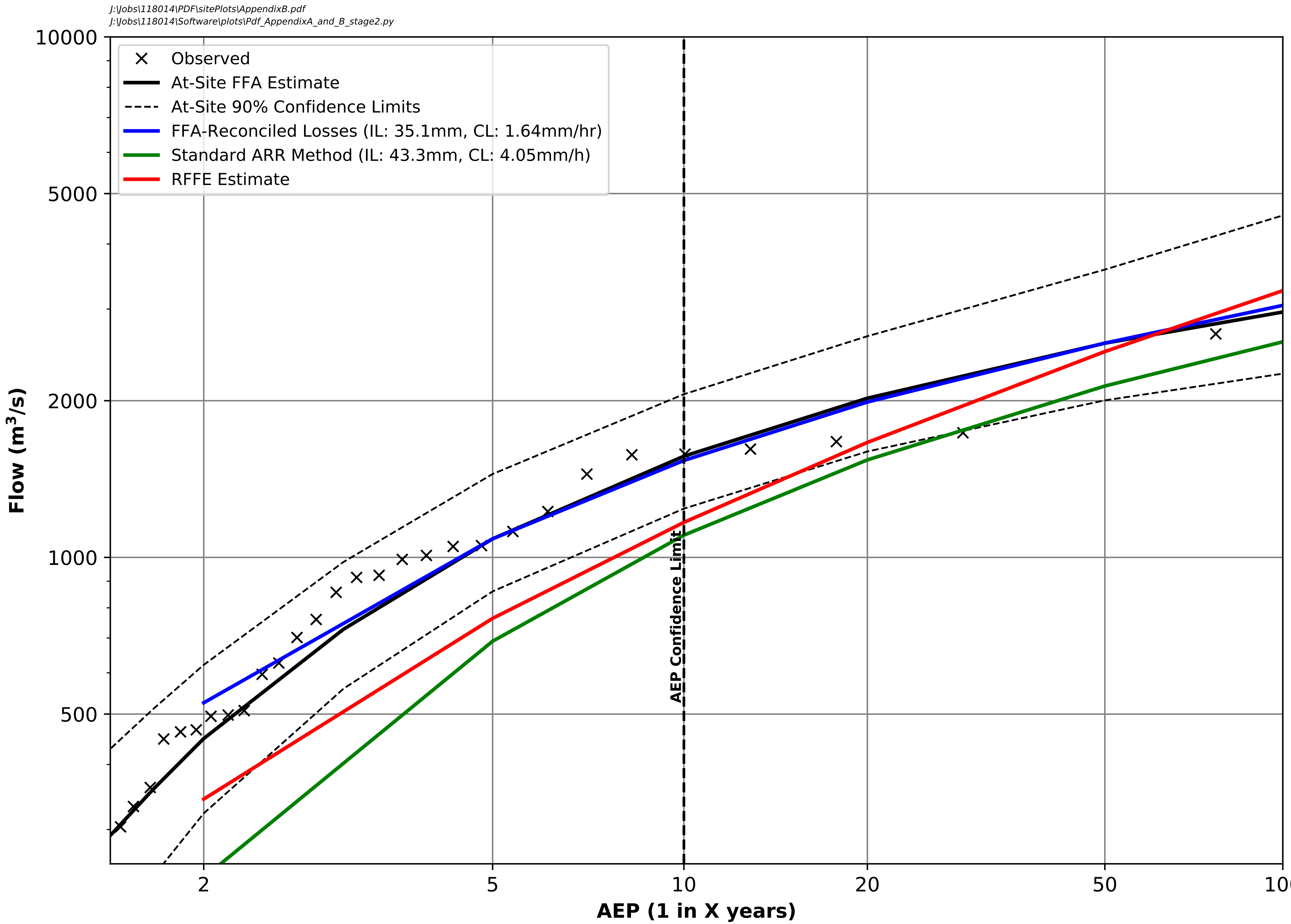
METHOD COMPARISON

CLOUDS CK - 204037 [I9]



NEWTON BOYD - 204034 [I10]
METHOD COMPARISON

APPENDIX B119



METHOD COMPARISON

WIANGAREE - 203005 [11]

APPENDIX B120

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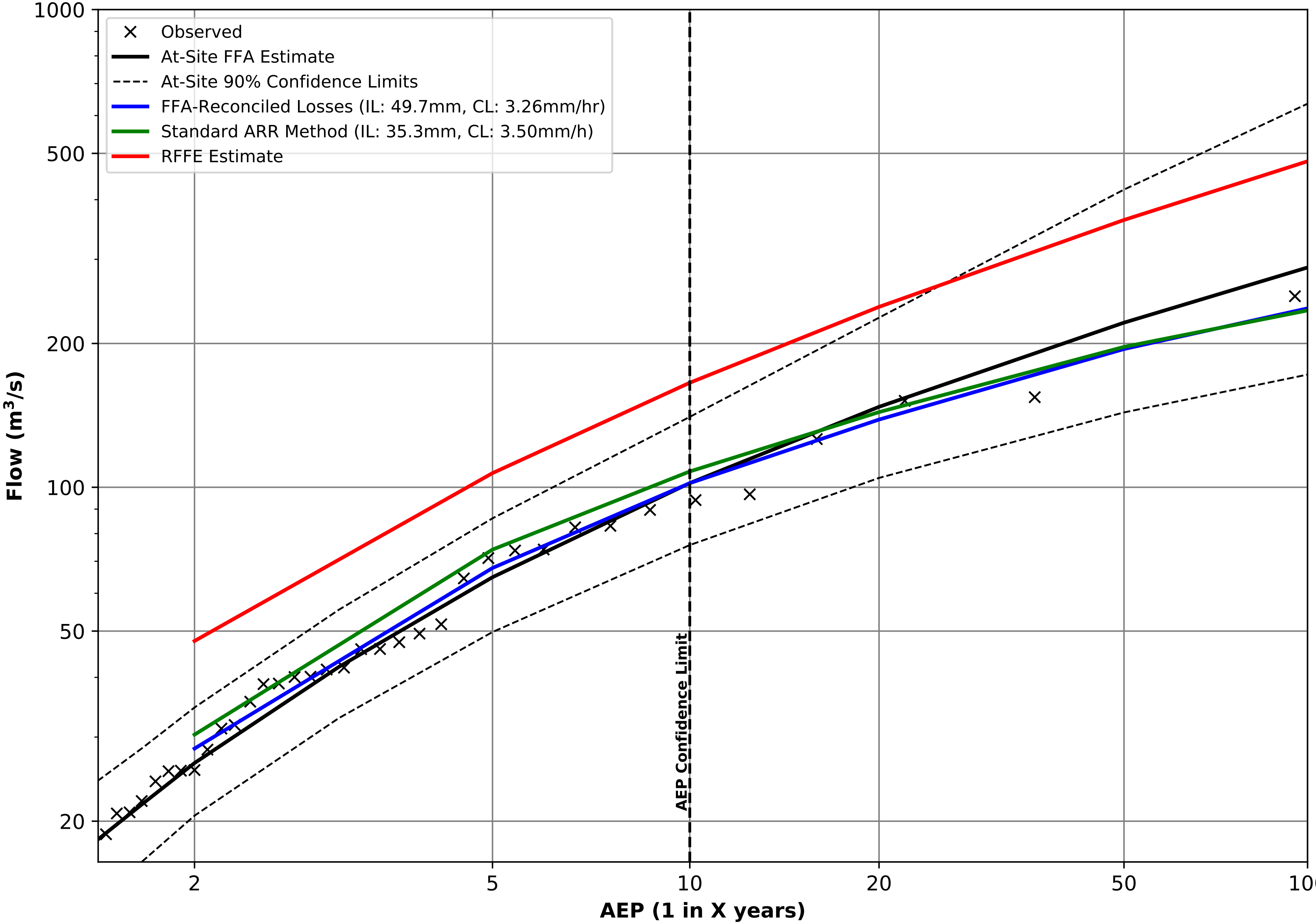

METHOD COMPARISON
BONALBO - 204043 [I12]

APPENDIX B121

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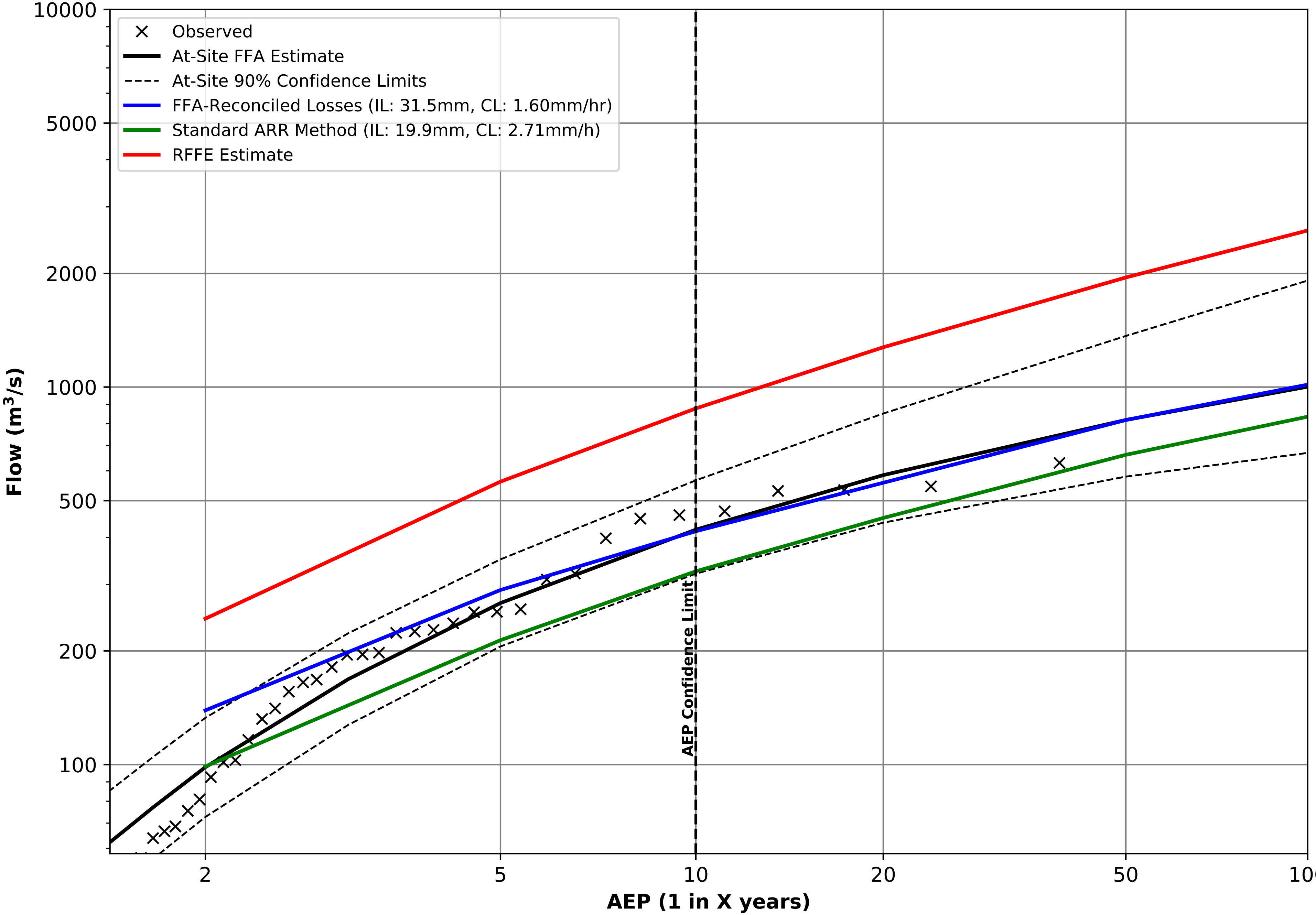
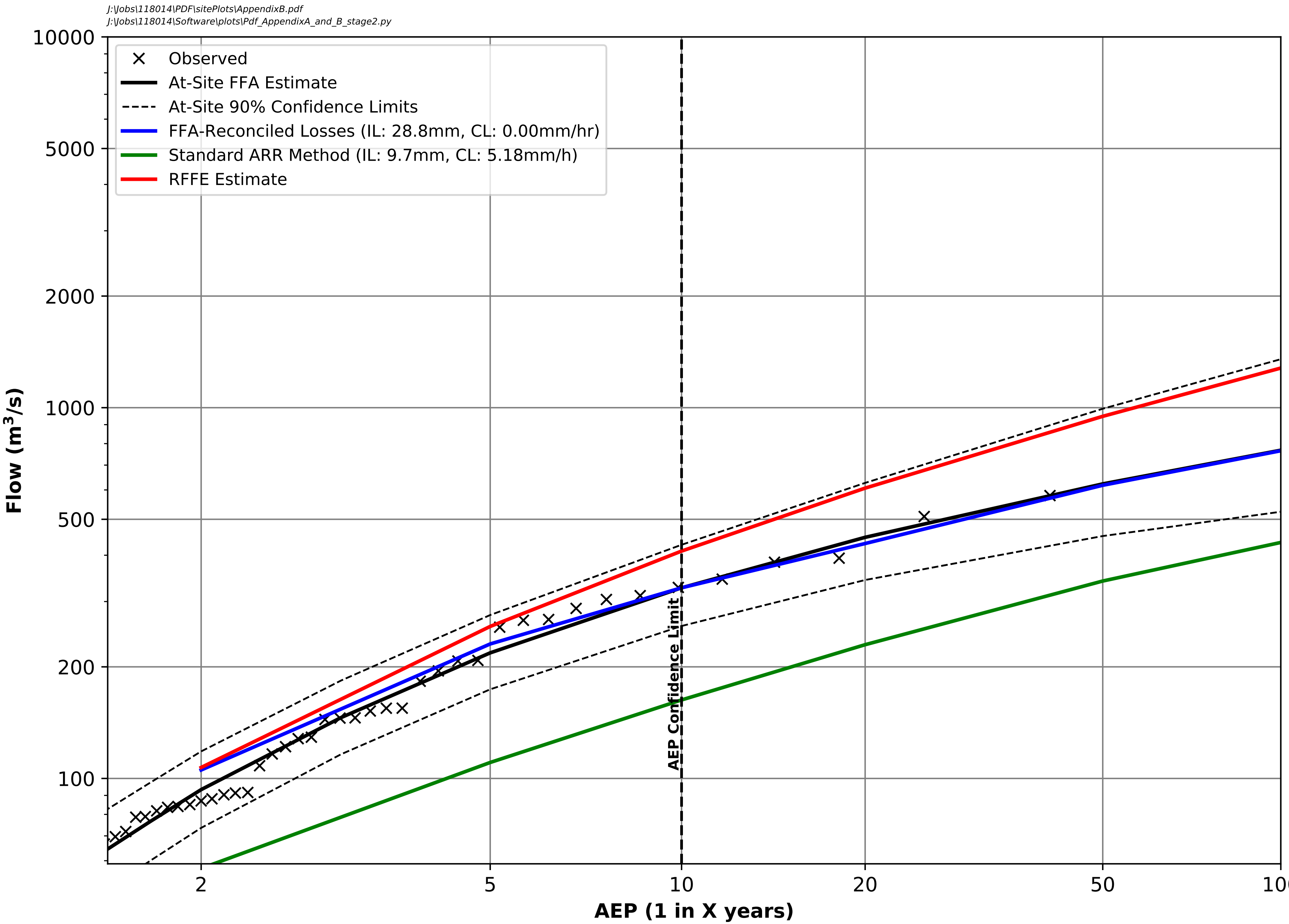


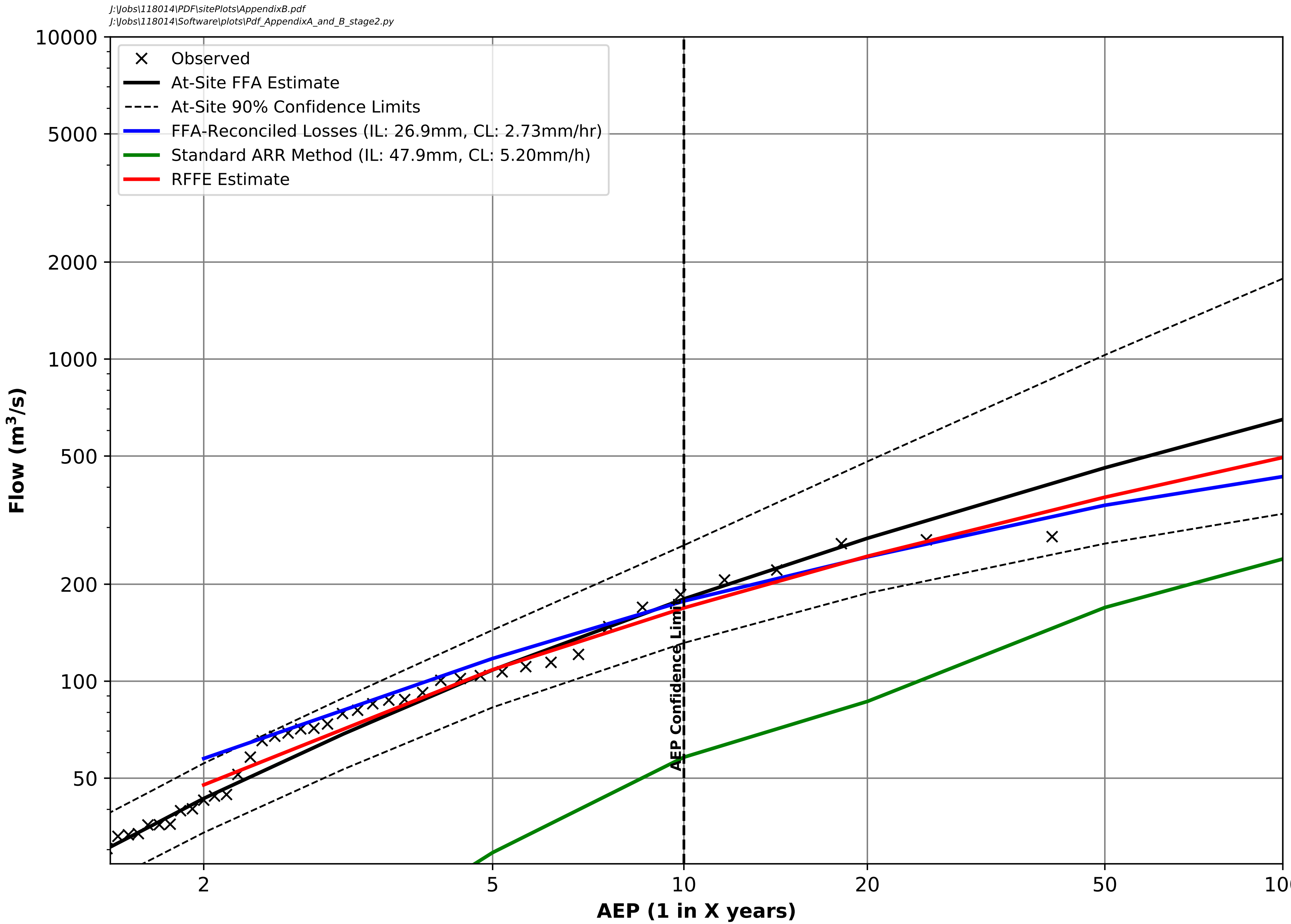
METHOD COMPARISON
APSLEY FALLS - 206018 [I13]

APPENDIX B122



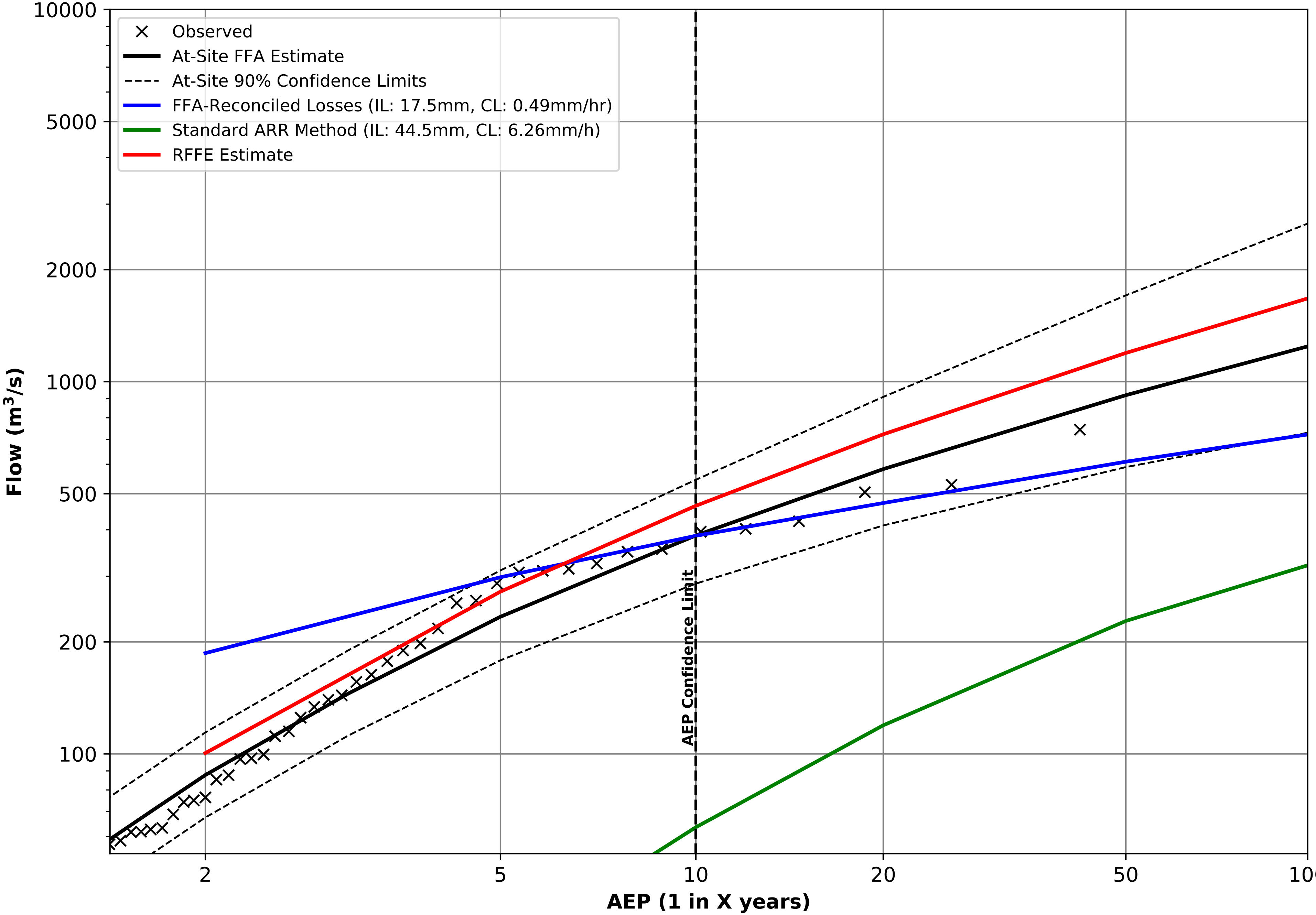
METHOD COMPARISON
CONINSIDE - 206014 [14]

APPENDIX B123



METHOD COMPARISON
TIA - 206009 [115]

APPENDIX B124



SANDY HILL(BELOW SNAKE CRE) - 204036 [I16]
METHOD COMPARISON

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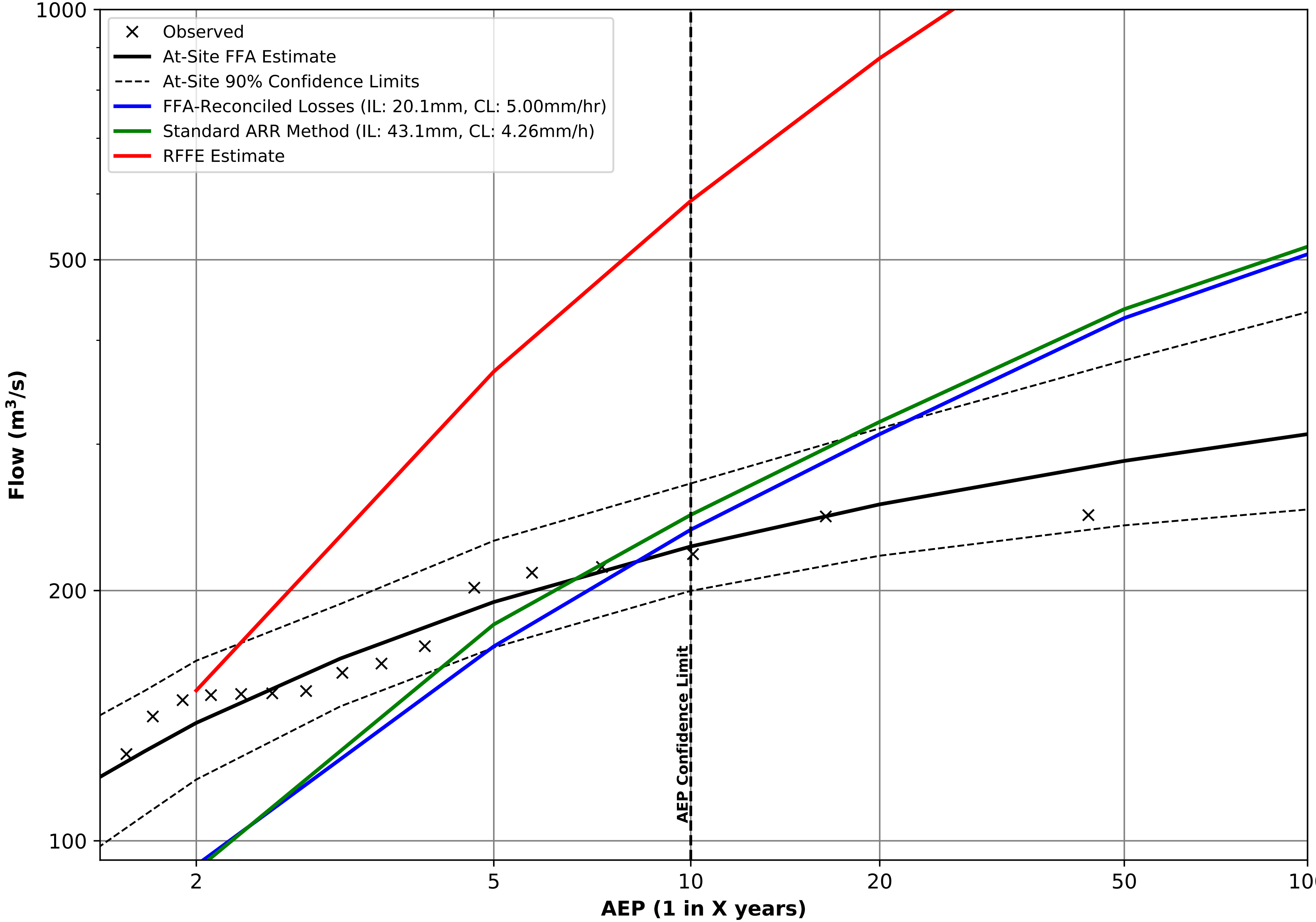

METHOD COMPARISON
GLENIFFER BR - 205014 [117]

APPENDIX B126

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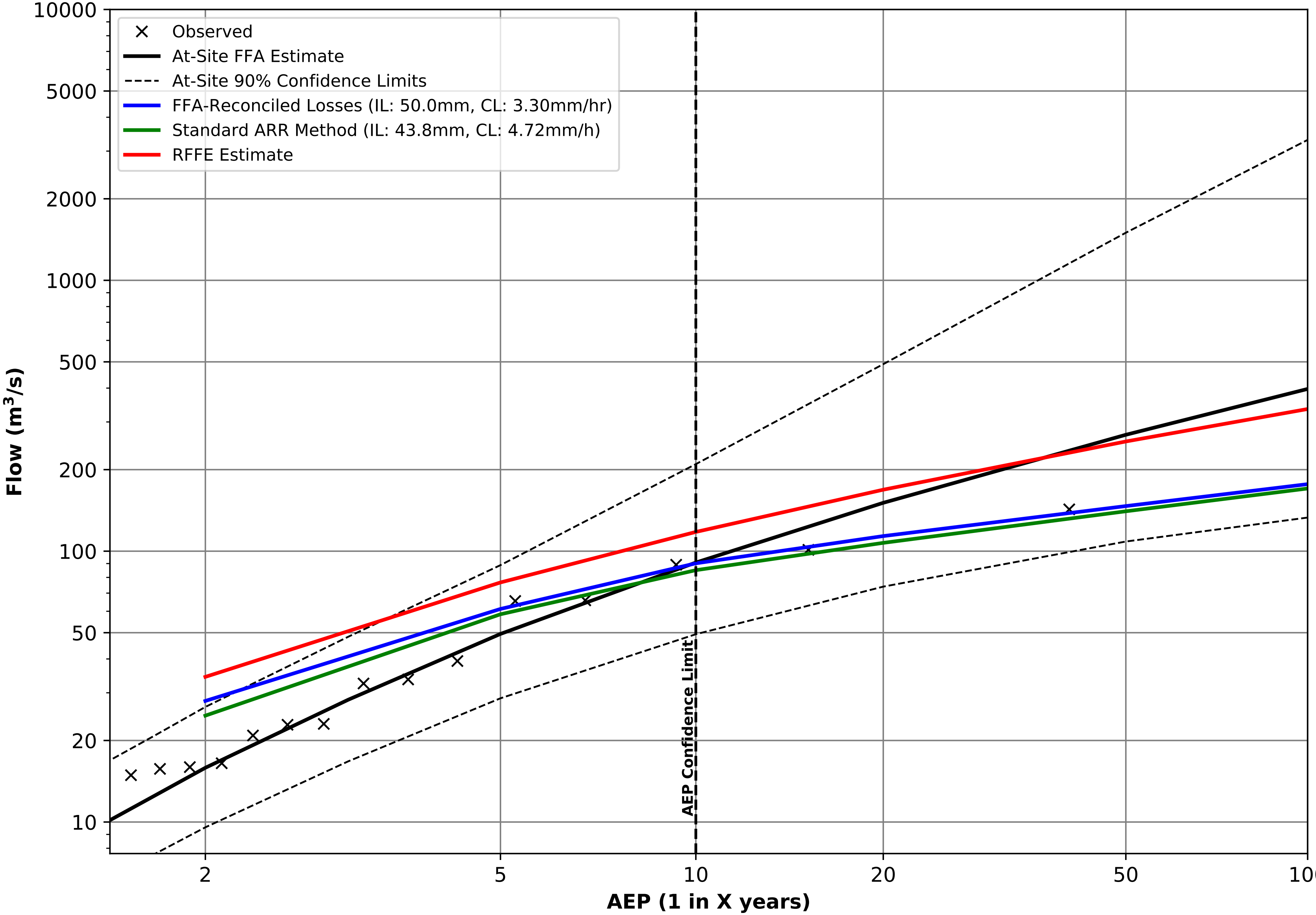

WOOLGOOLGA - 205007 [18]
METHOD COMPARISON

APPENDIX B127

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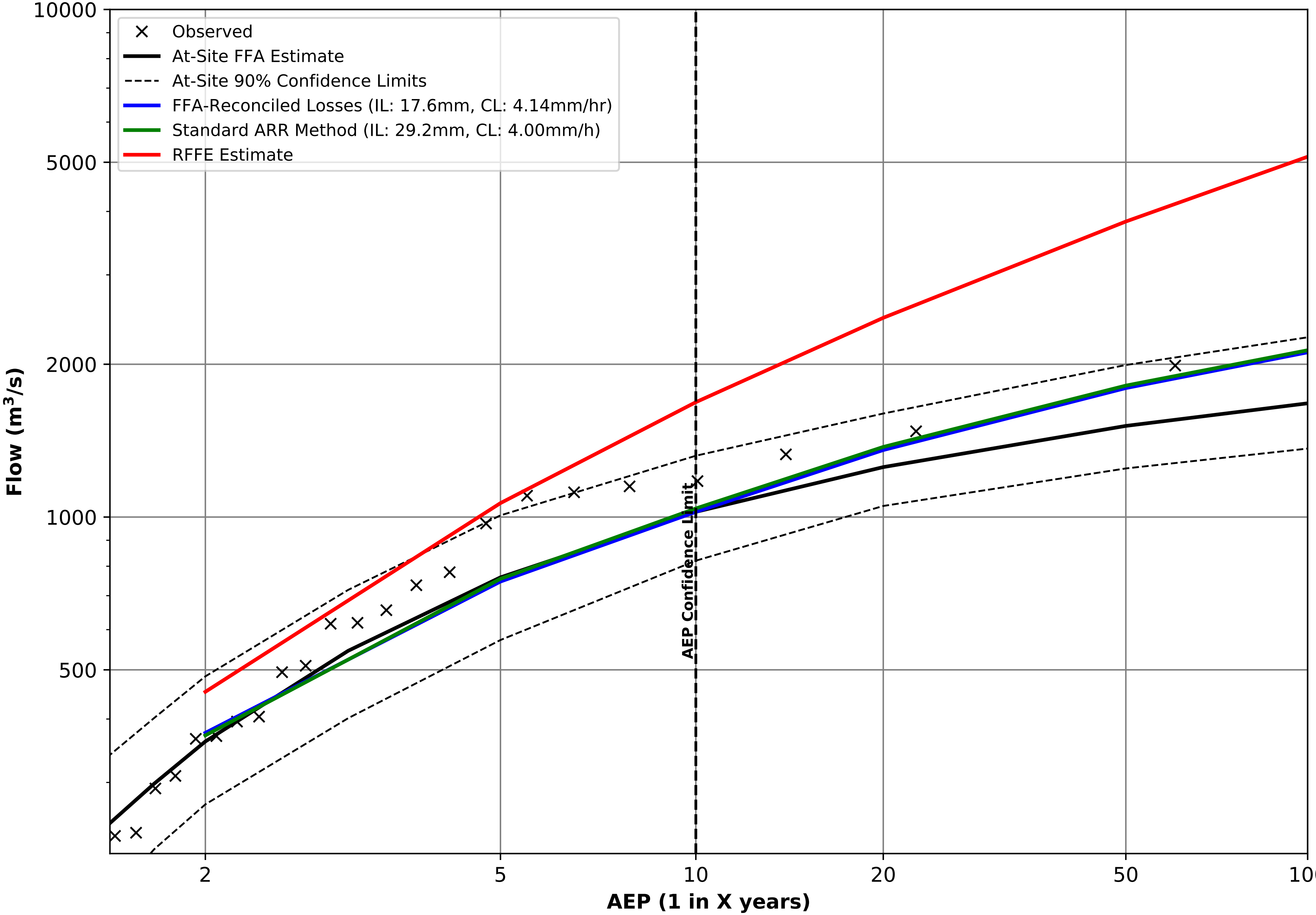
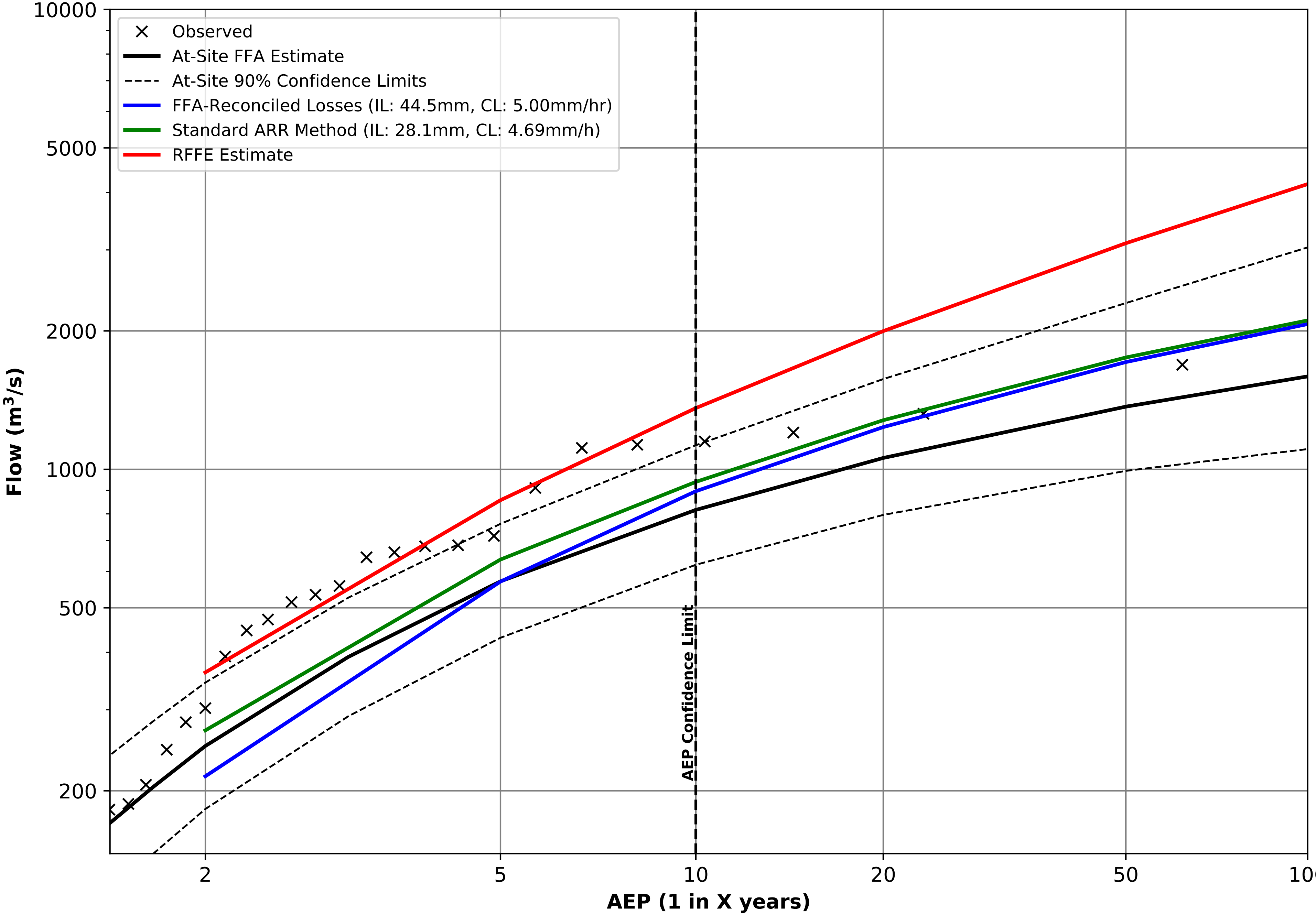


METHOD COMPARISON
BOWRAVILLE - 205006 [119]

APPENDIX B128



METHOD COMPARISON
THORA - 205002 [I20]

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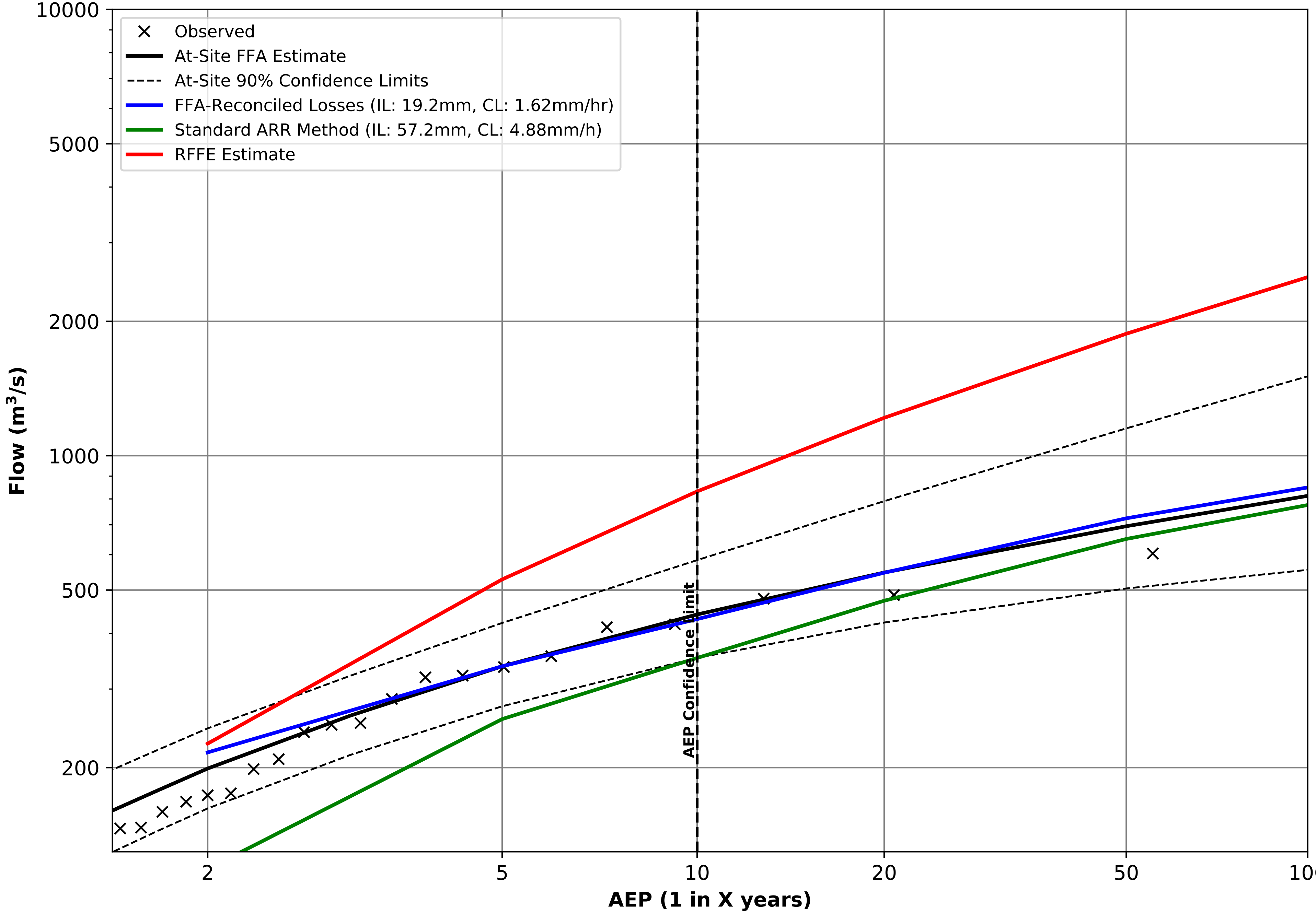

METHOD COMPARISON
BOBO NURSERY - 204026 [I21]

APPENDIX B130

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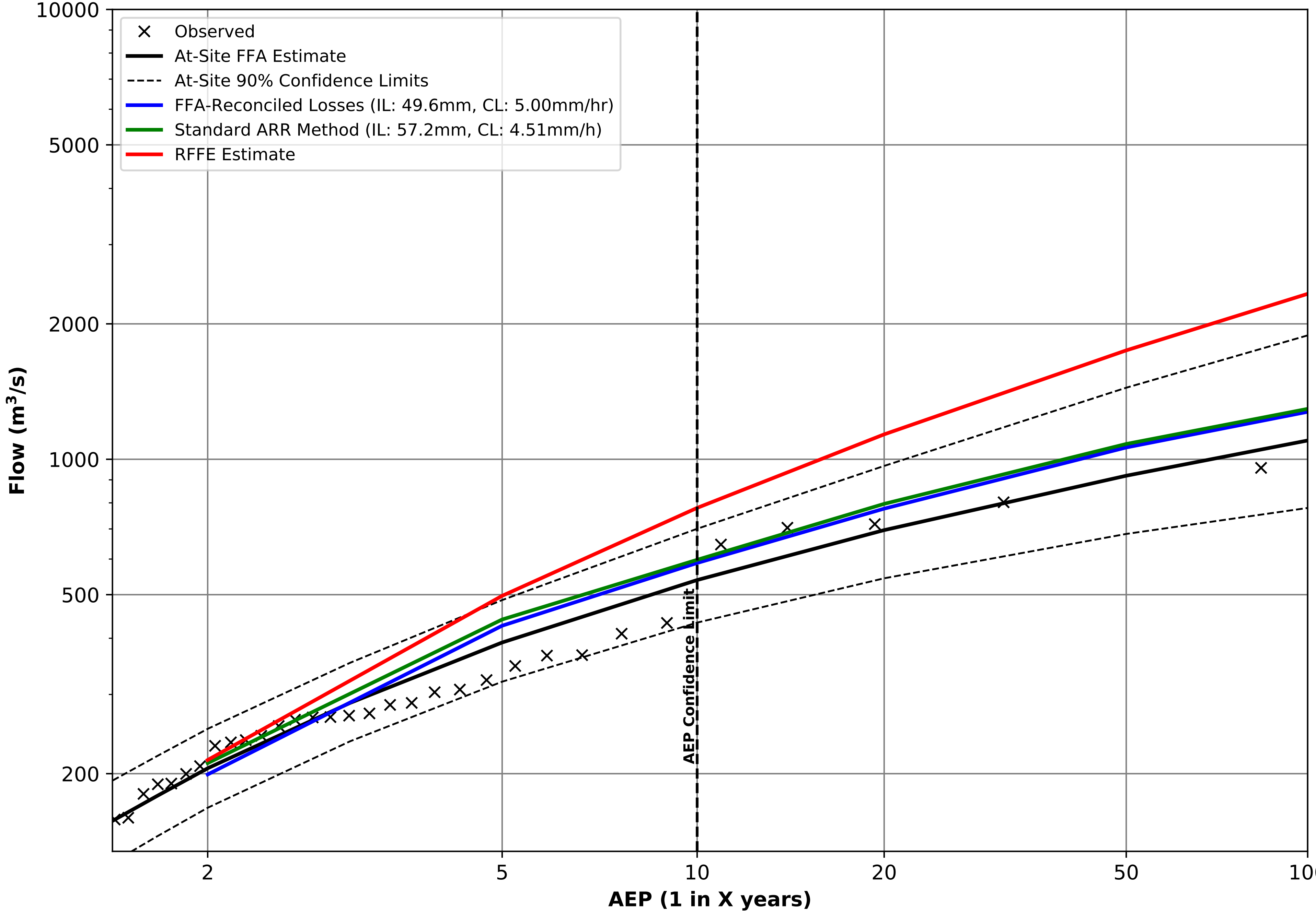

METHOD COMPARISON
KARANGI - 204025 [I22]

APPENDIX B131

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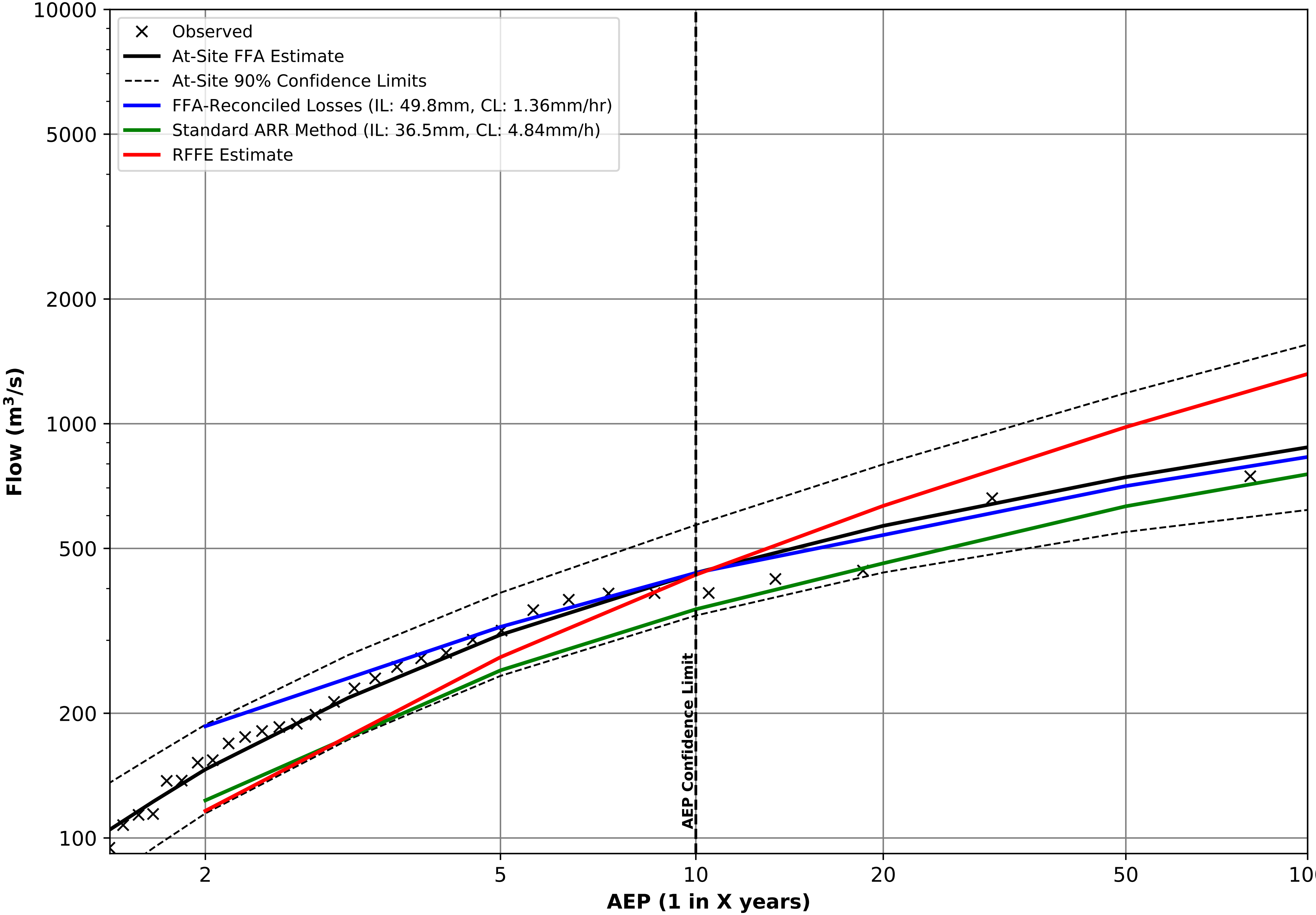

METHOD COMPARISON
DORRIGO NO.2 & NO.3 - 204017 [I23]

APPENDIX B132

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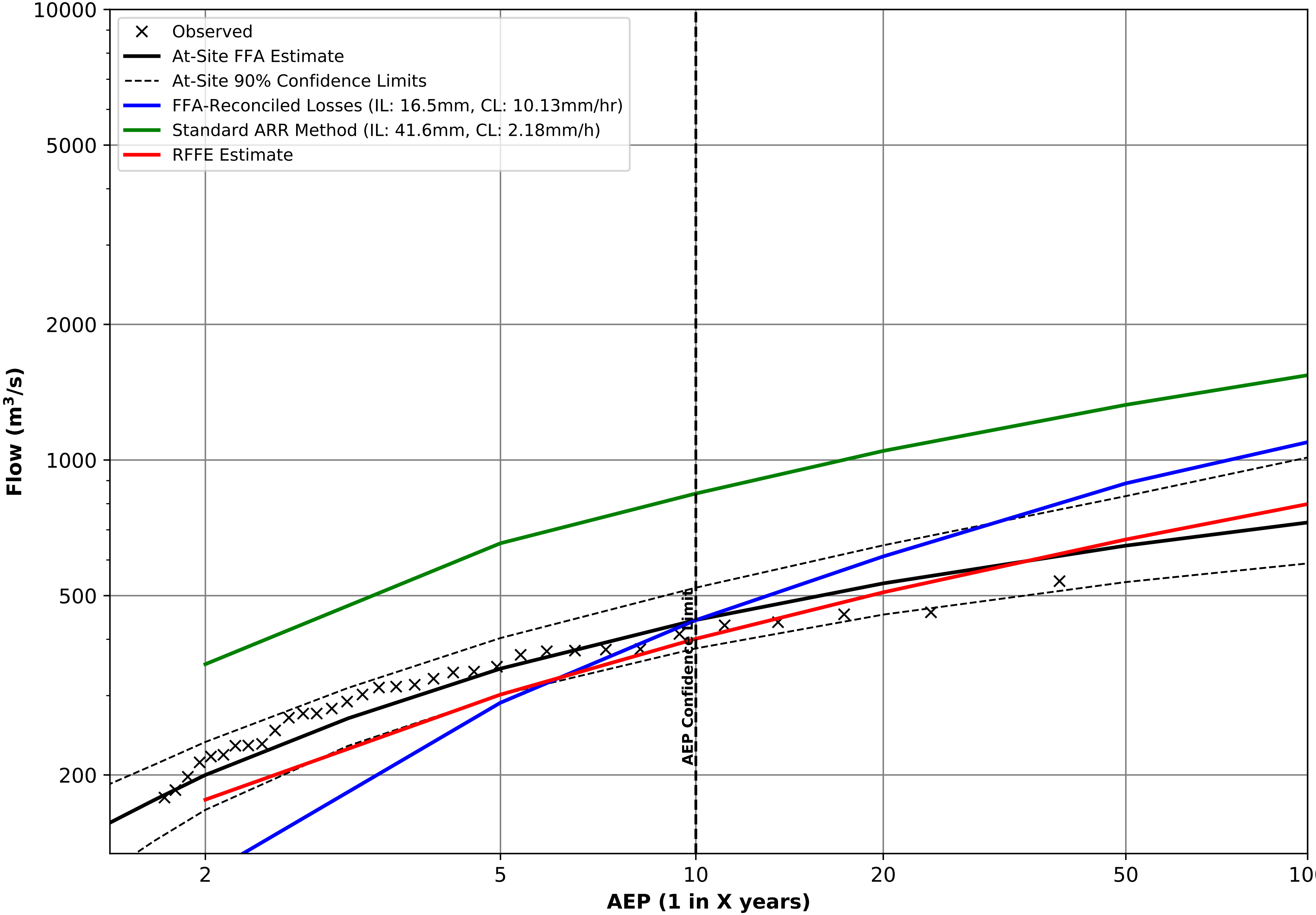
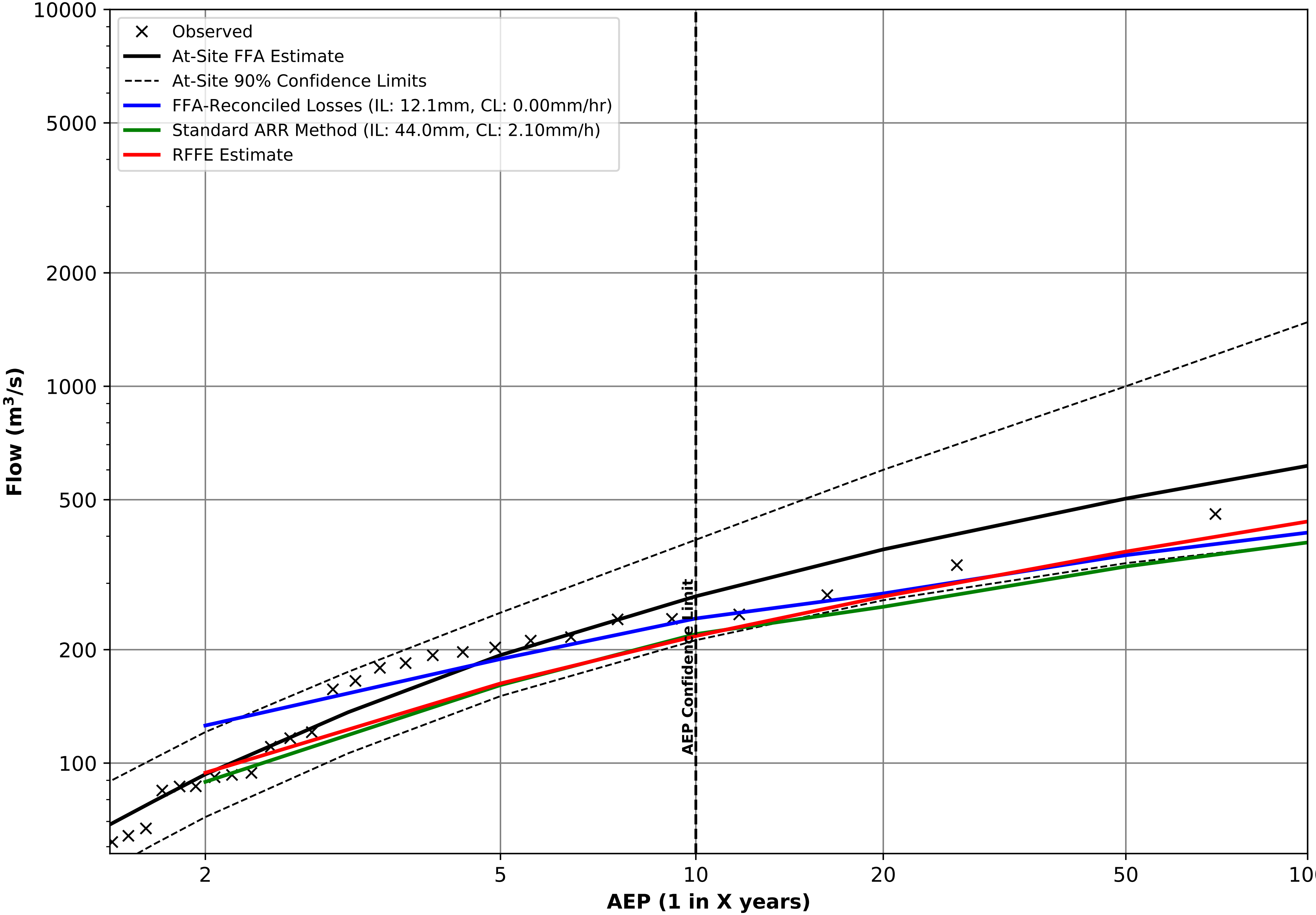


METHOD COMPARISON
ELTHAM - 203014 [I24]



METHOD COMPARISON
BINNA BURRA - 203012 [I25]

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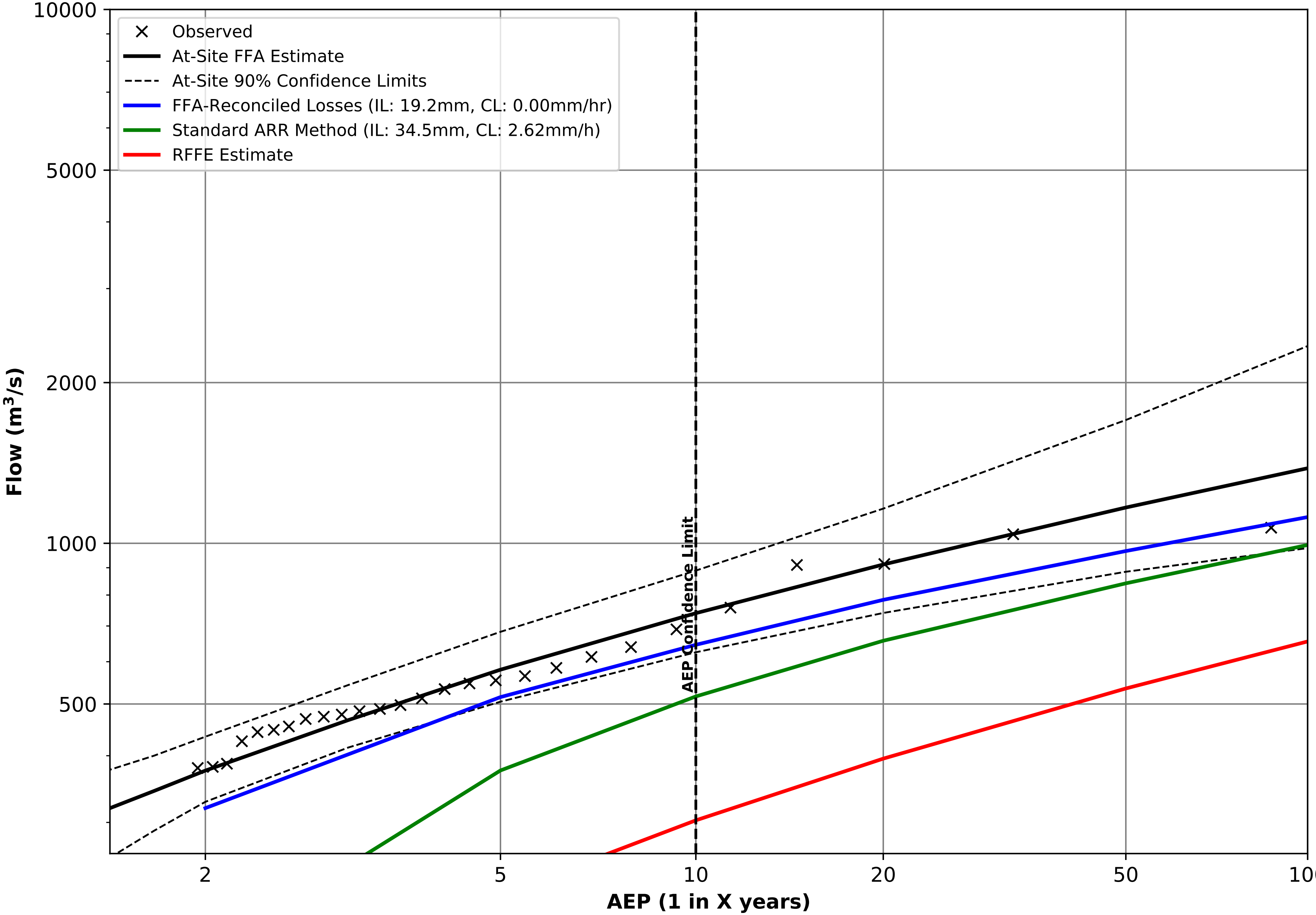

METHOD COMPARISON
ROCK VALLEY - 203010 [I26]

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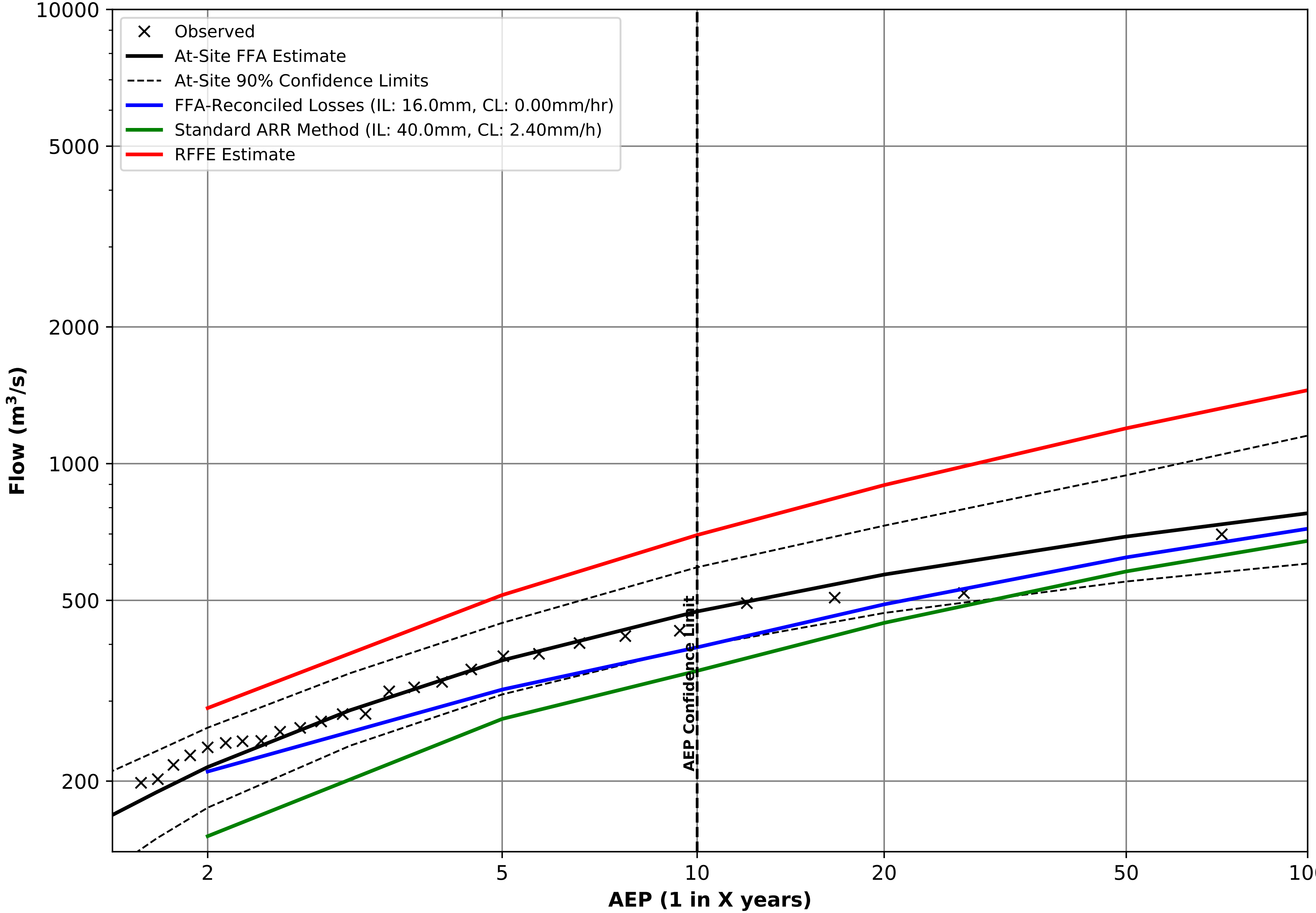
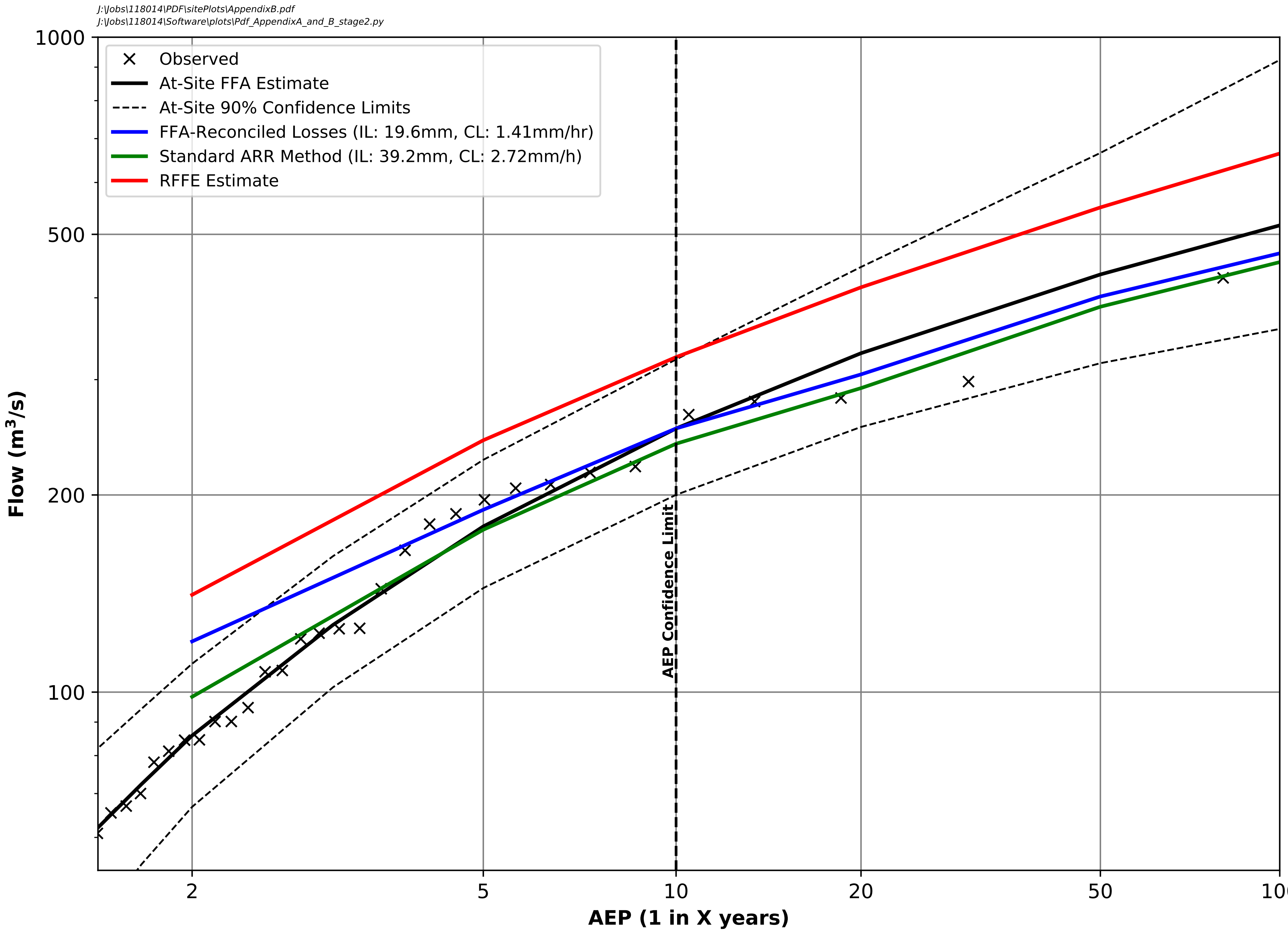


METHOD COMPARISON
REPENTANCE - 203002 [I27]

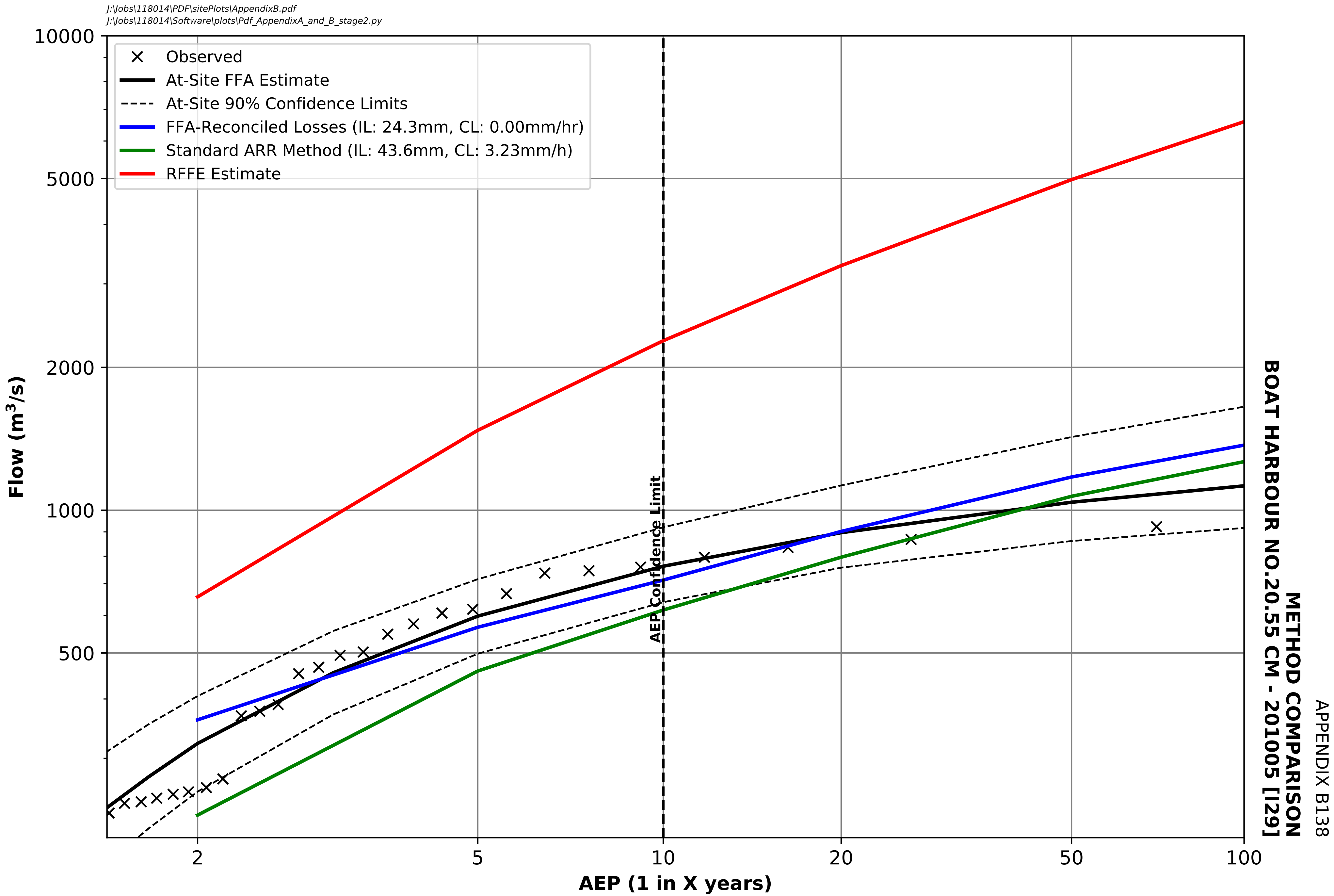
APPENDIX B136



DURRUMBUL (SHERRYS CROSSING) - 202001 [I28]

METHOD COMPARISON

APPENDIX B137



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Observed
At-Site FFA Estimate
At-Site 90% Confidence Limits
FFA-Reconciled Losses (IL: 24.3mm, CL: 0.00mm/hr)
Standard ARR Method (IL: 43.6mm, CL: 3.23mm/h)
RFFE Estimate
AEP Confidence Limit
Flow (m³/s)
10000
5000
2000
1000
500
2
5
10
20
50
100
AEP (1 in X years)
BOAT HARBOUR NO.20.55 CM - 201005 [I29]
METHOD COMPARISON
APPENDIX B138

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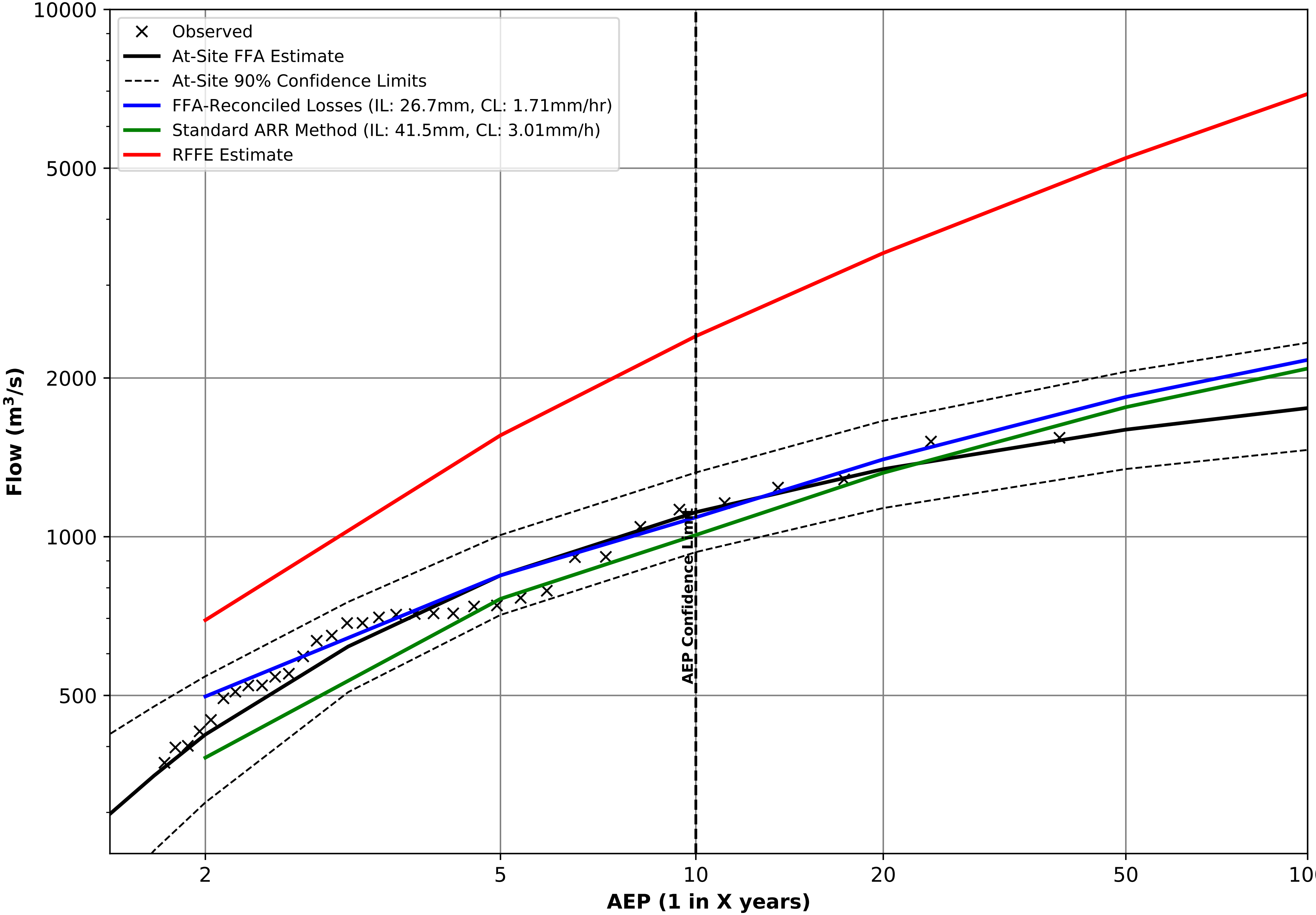
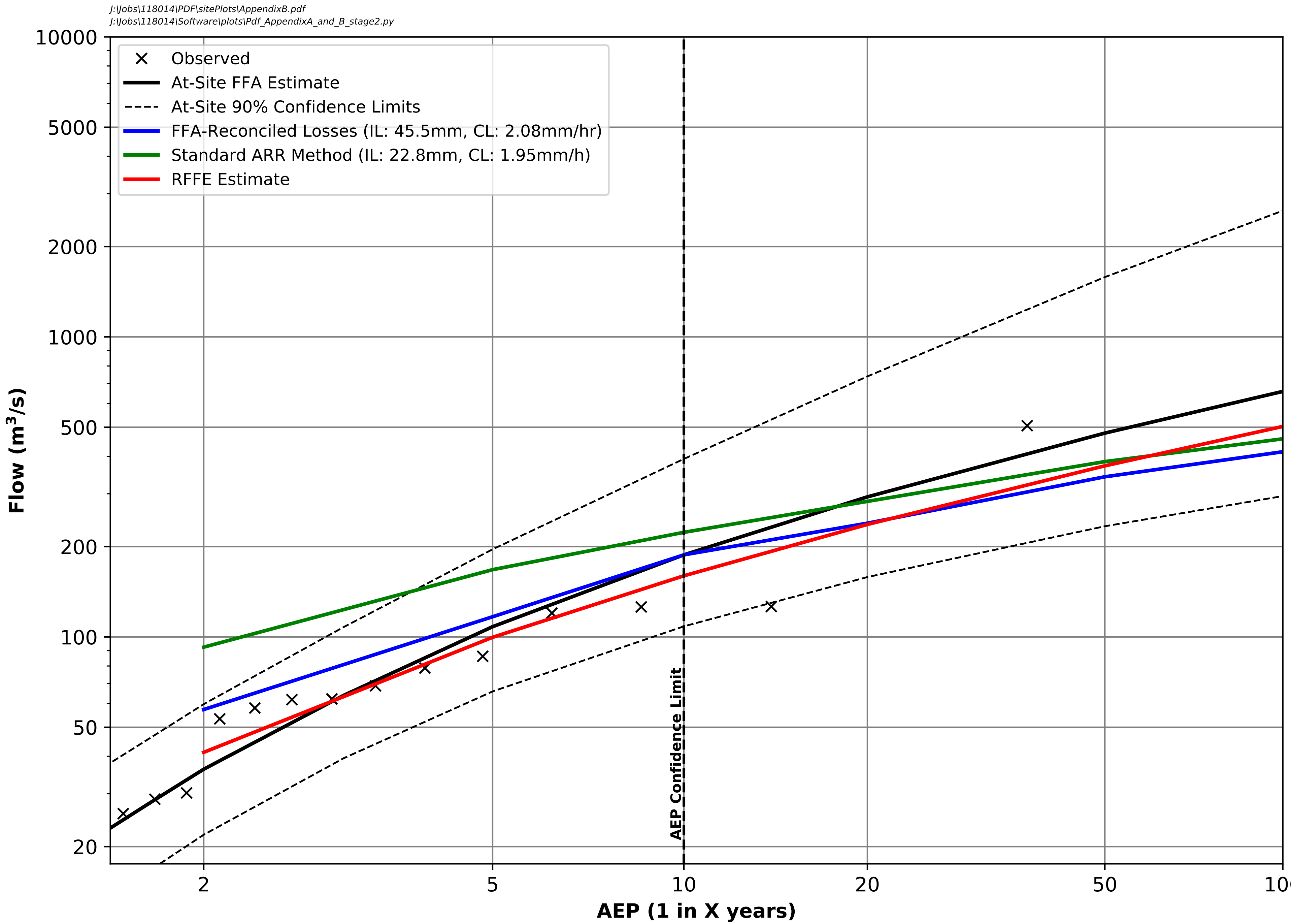


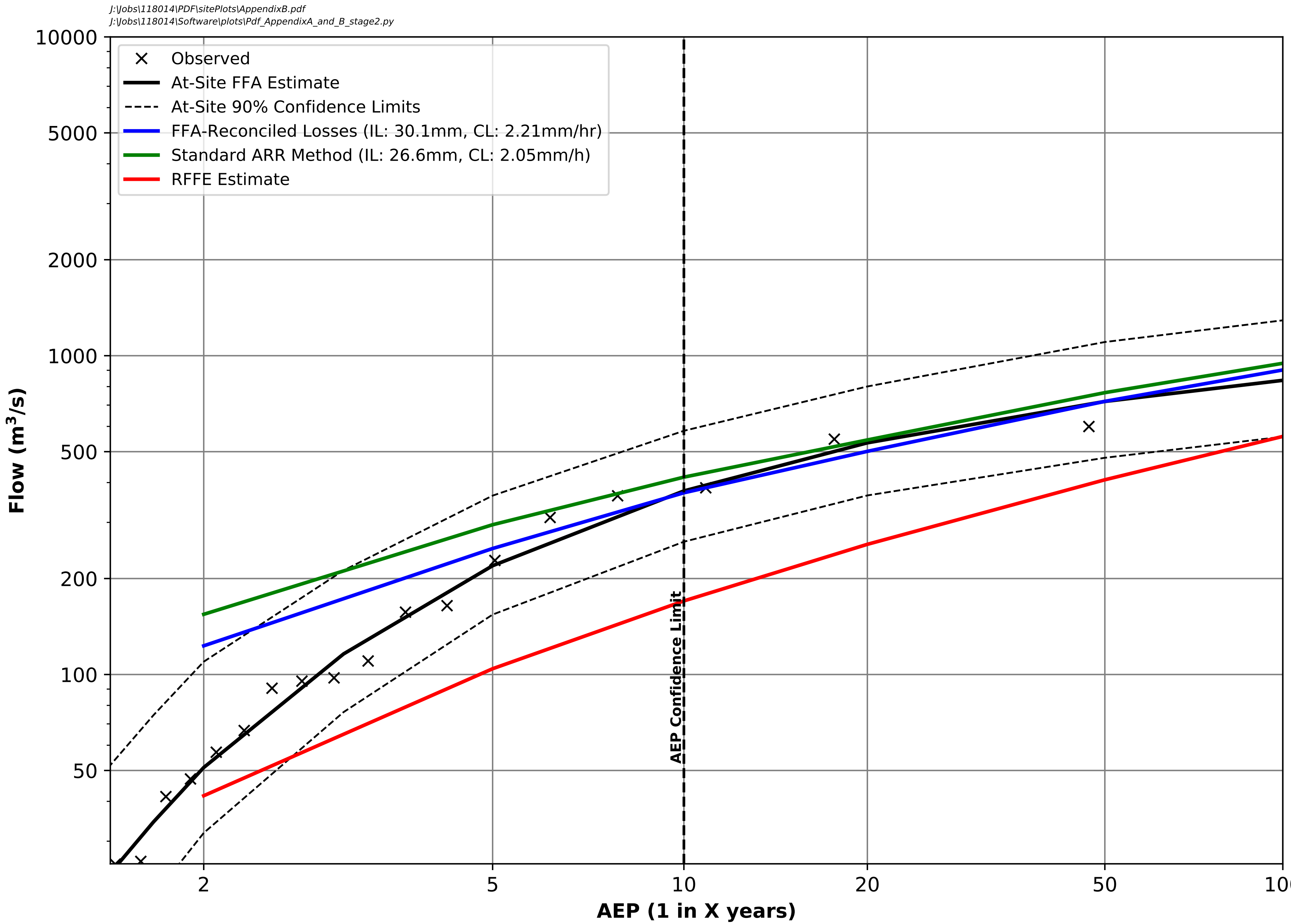
METHOD COMPARISON
EUNGELLA - 201001 [I30]

APPENDIX B139



METHOD COMPARISON
DAMSITE - 419044 [J1]

APPENDIX B140



METHOD COMPARISON
WOODSREEF - 419047 [J2]

APPENDIX B141

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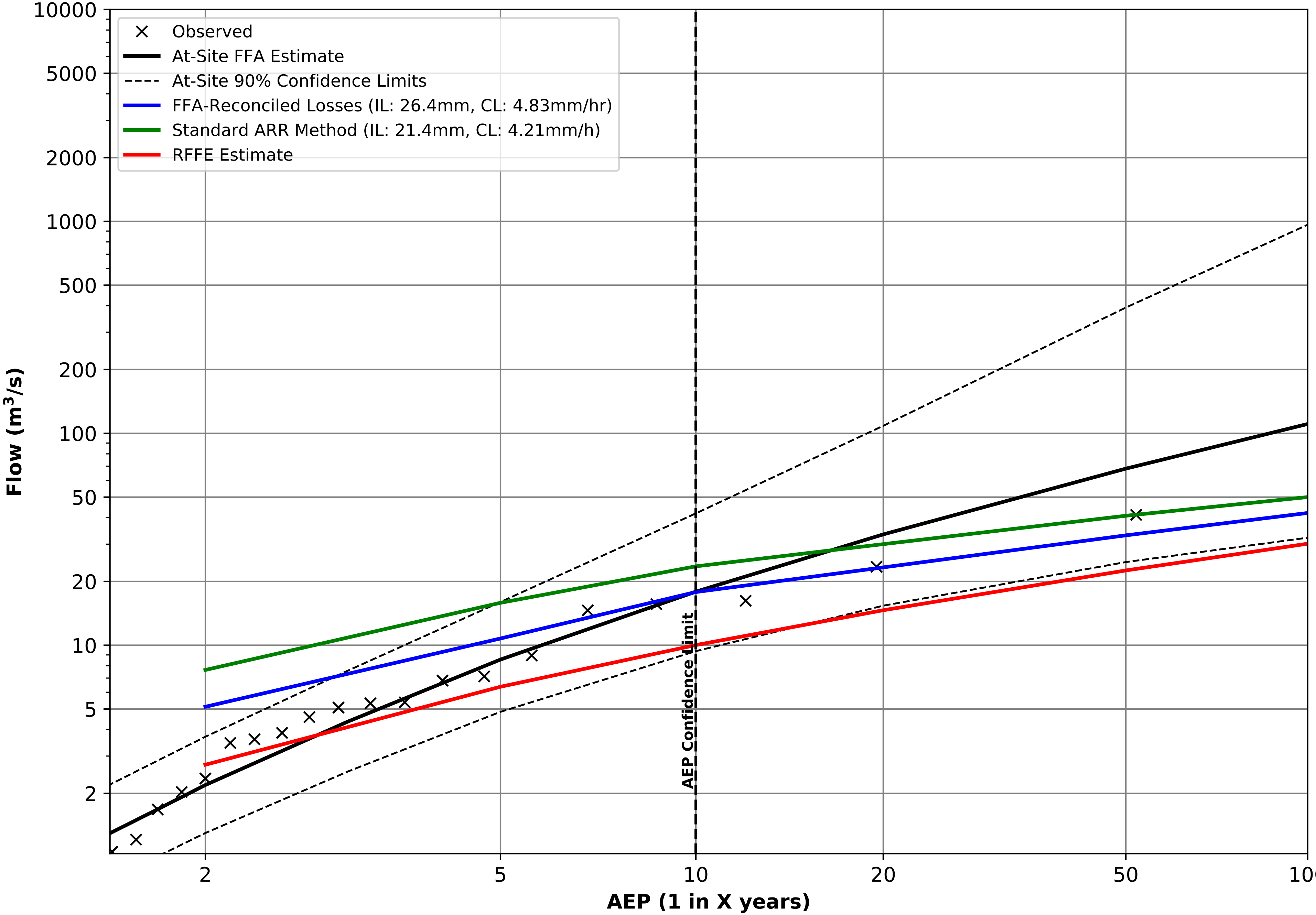

METHOD COMPARISON
BLACK MOUNTAIN - 418034 [J3]

APPENDIX B142

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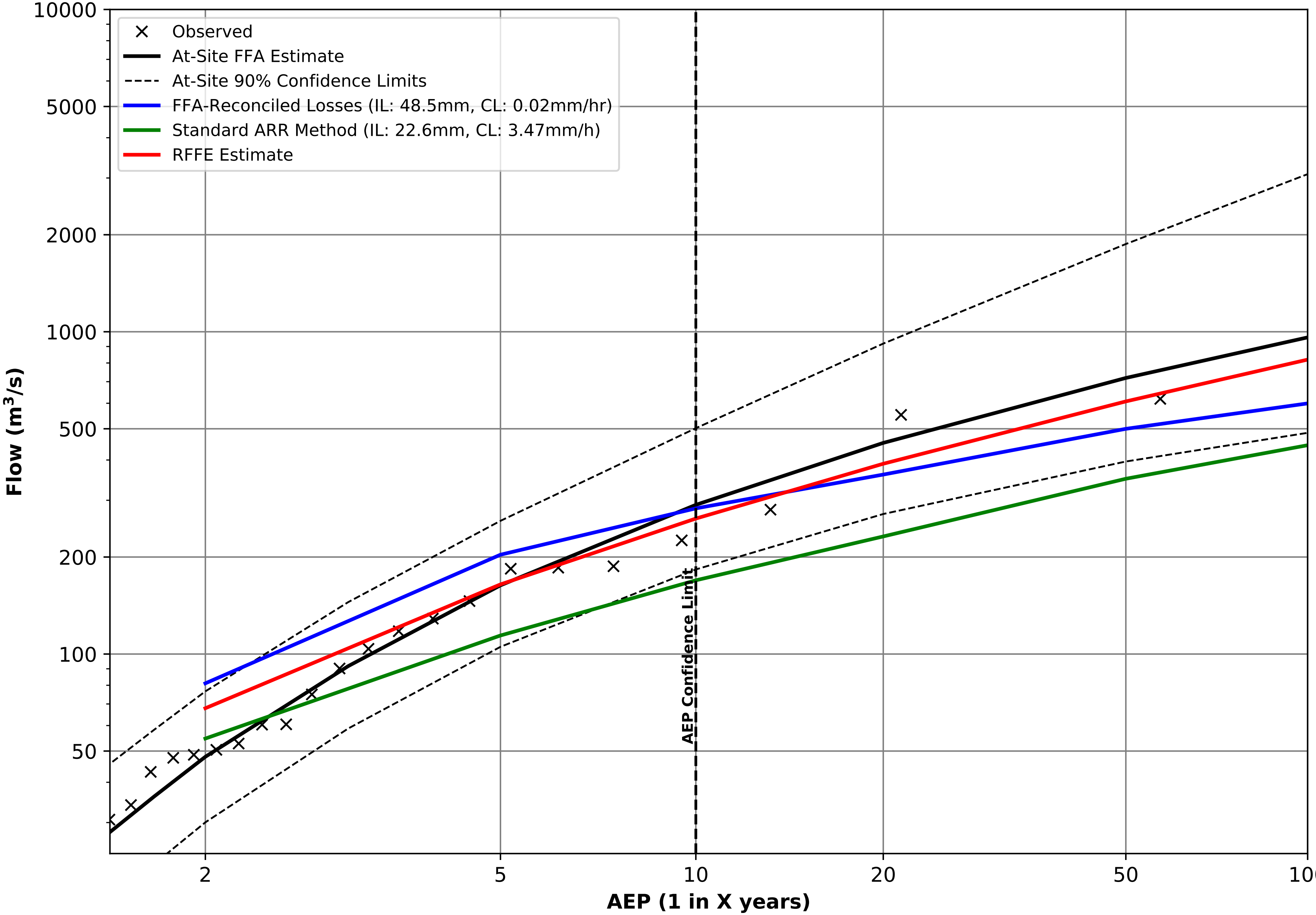
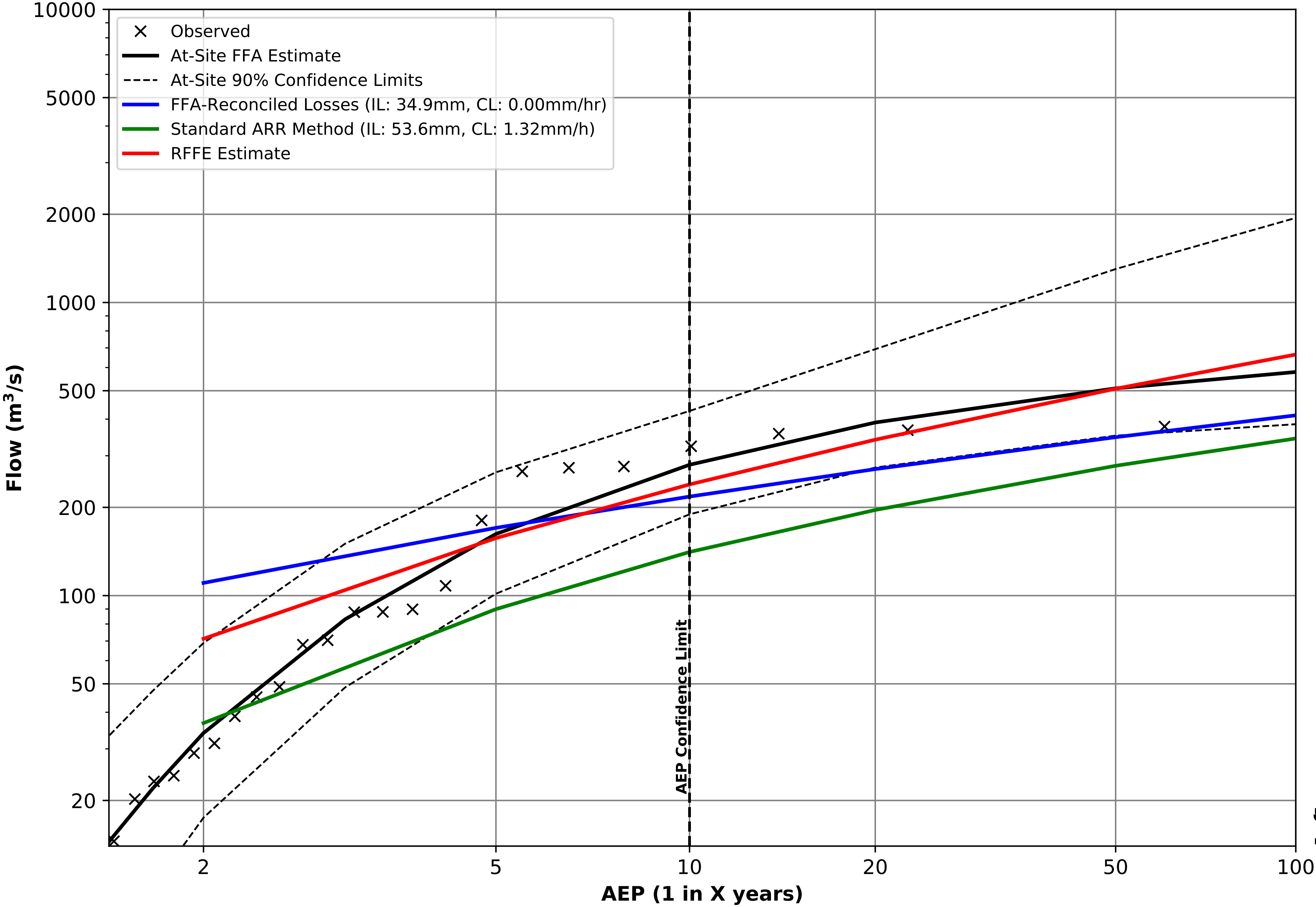


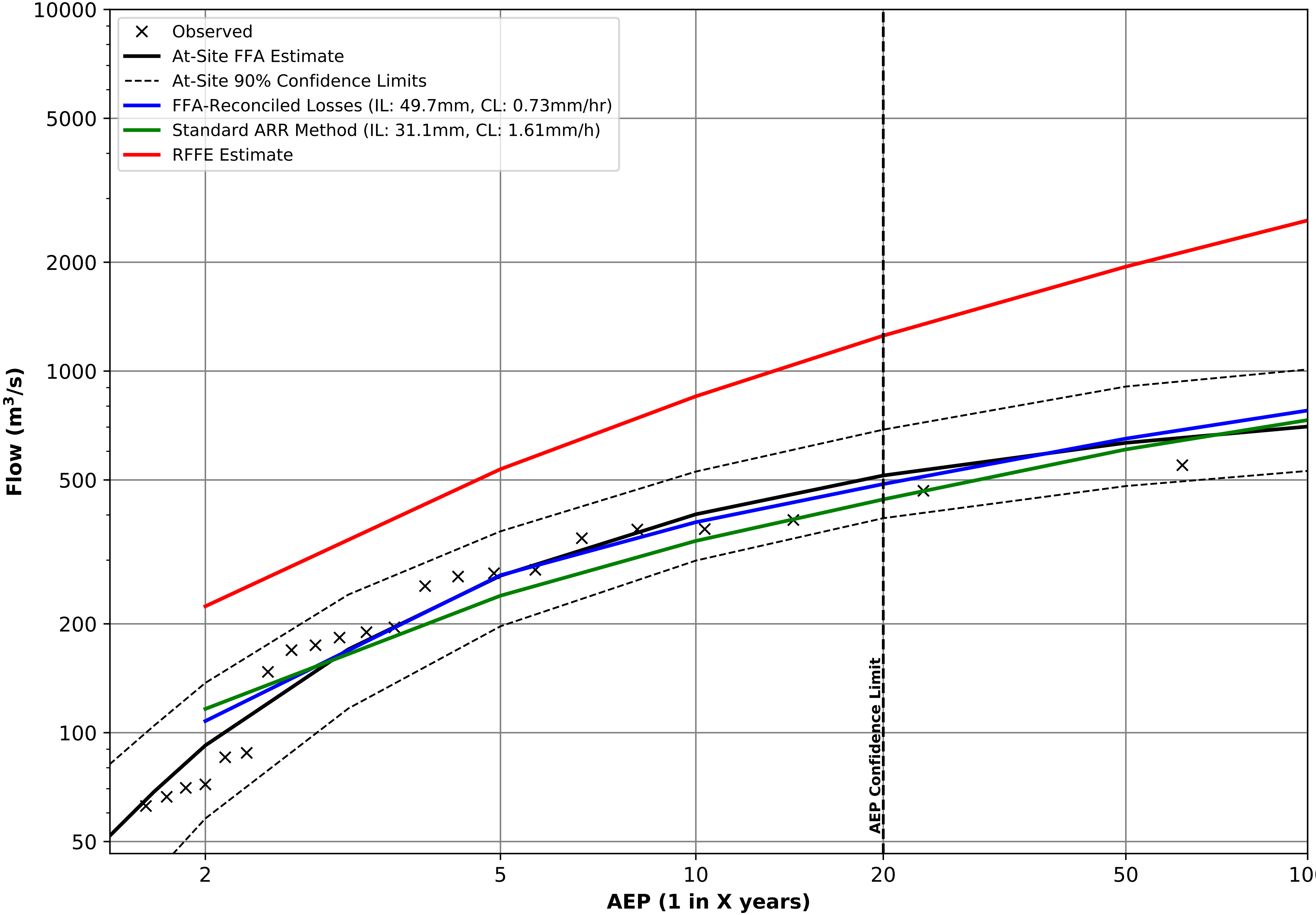
METHOD COMPARISON
SHANNON VALE - 204031 [J4]

APPENDIX B143



OLD WARRAH - 419076 [J5]
METHOD COMPARISON

APPENDIX B144



METHOD COMPARISON
TIMBUMBURI - 419035 [J6]

APPENDIX B145

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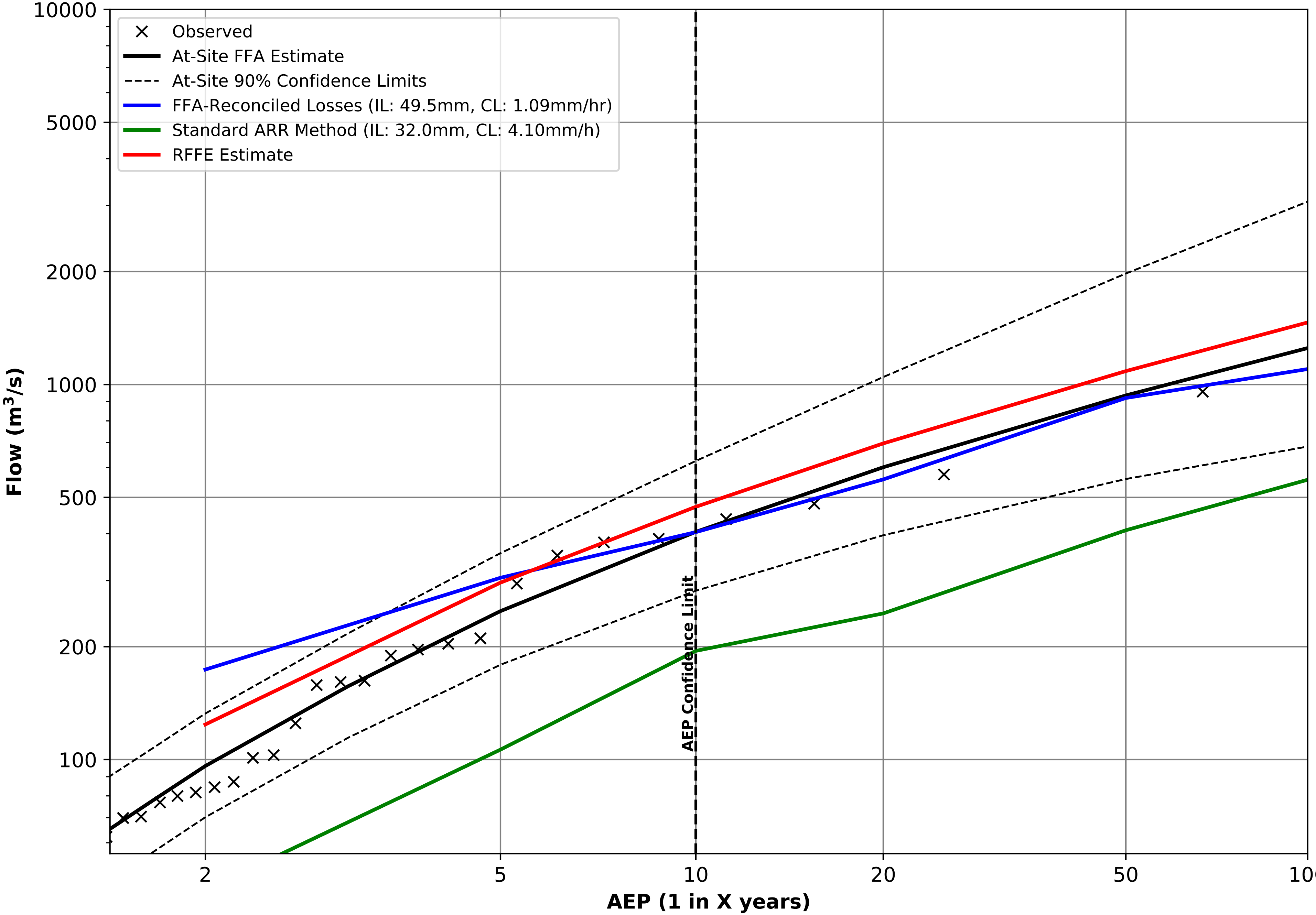
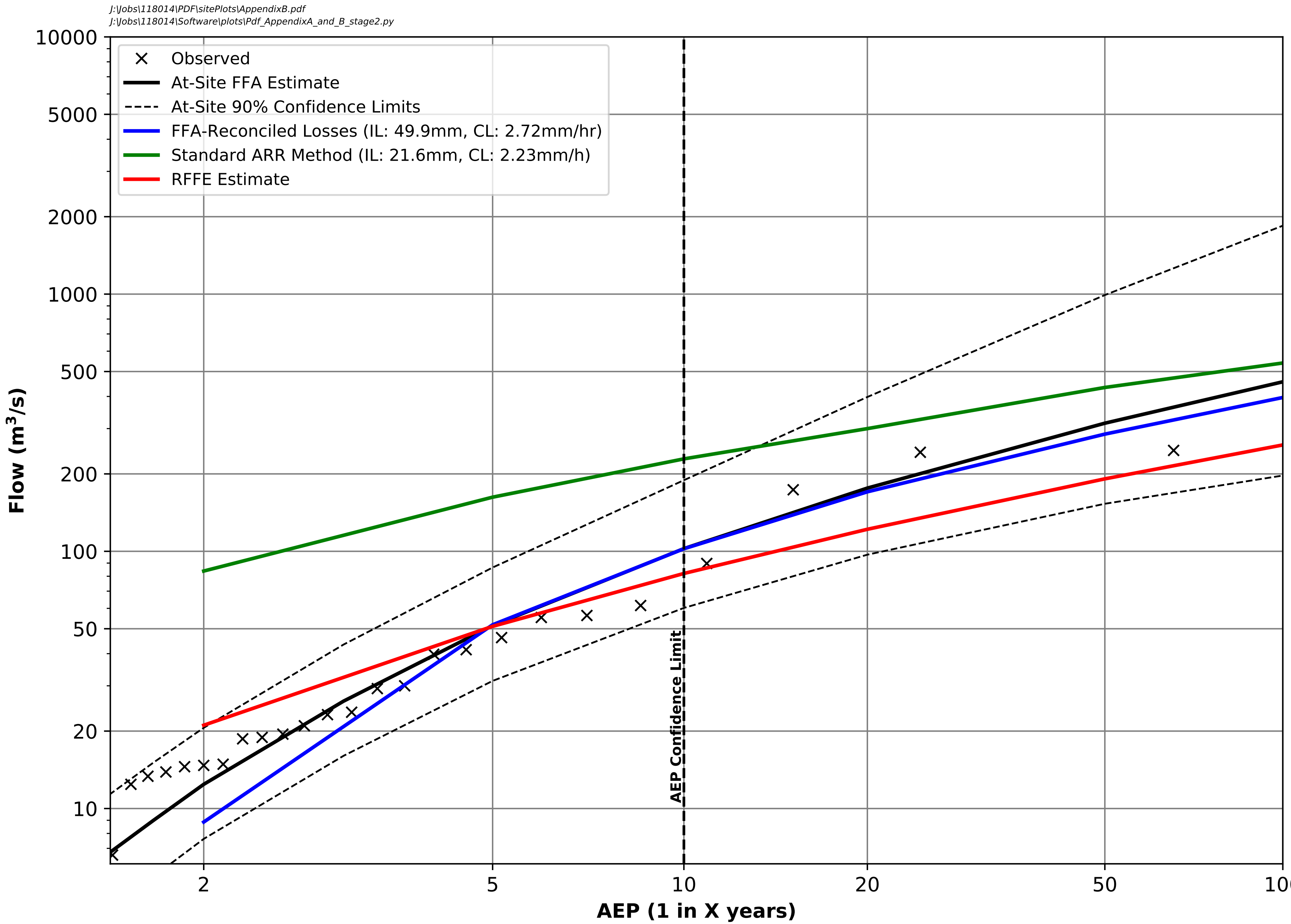
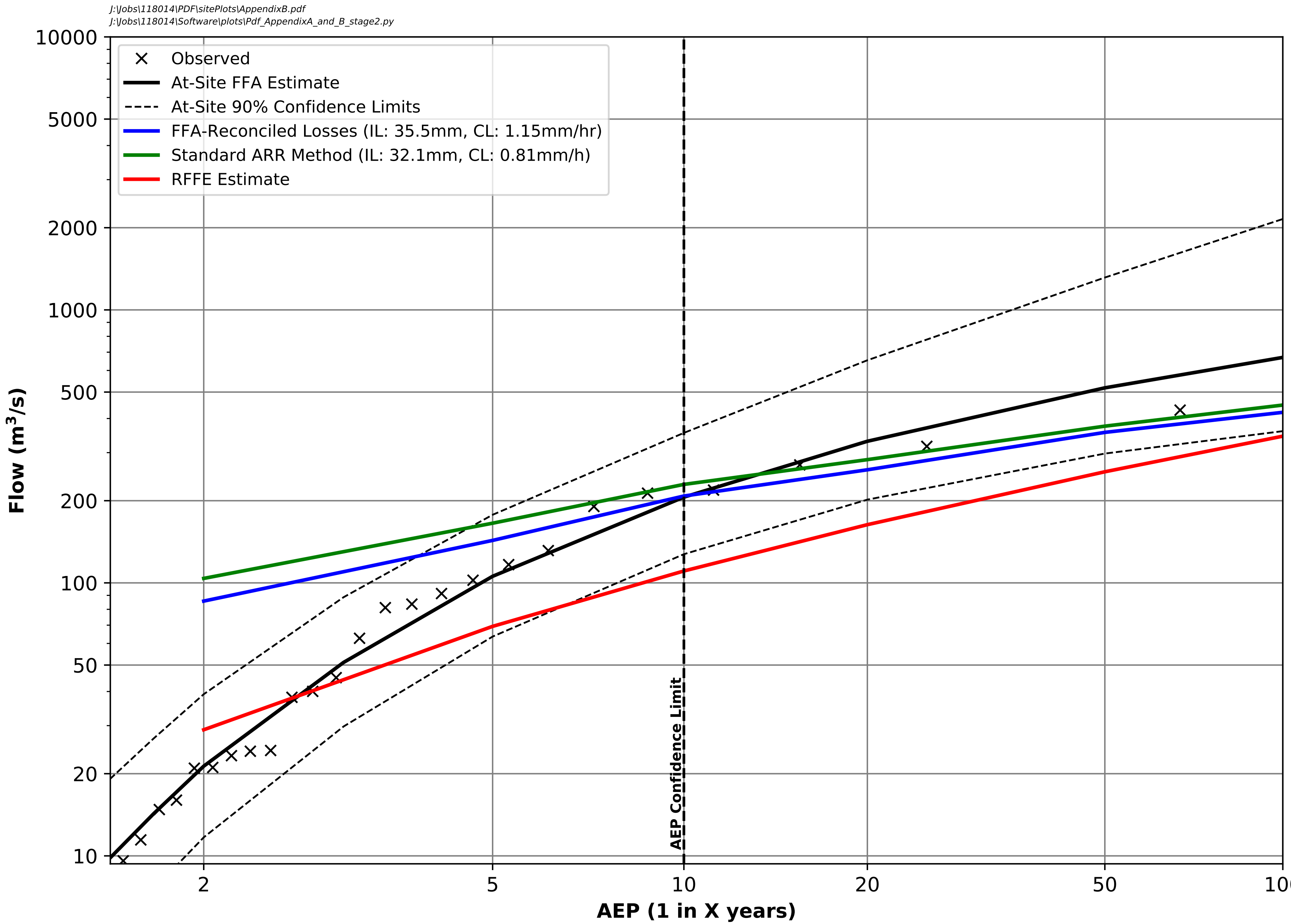


METHOD COMPARISON
WOOLBROOK - 419010 [J7]



METHOD COMPARISON
UKOLAN - 419029 [J8]



METHOD COMPARISON
BINGARA - 418025 [J9]

APPENDIX B148

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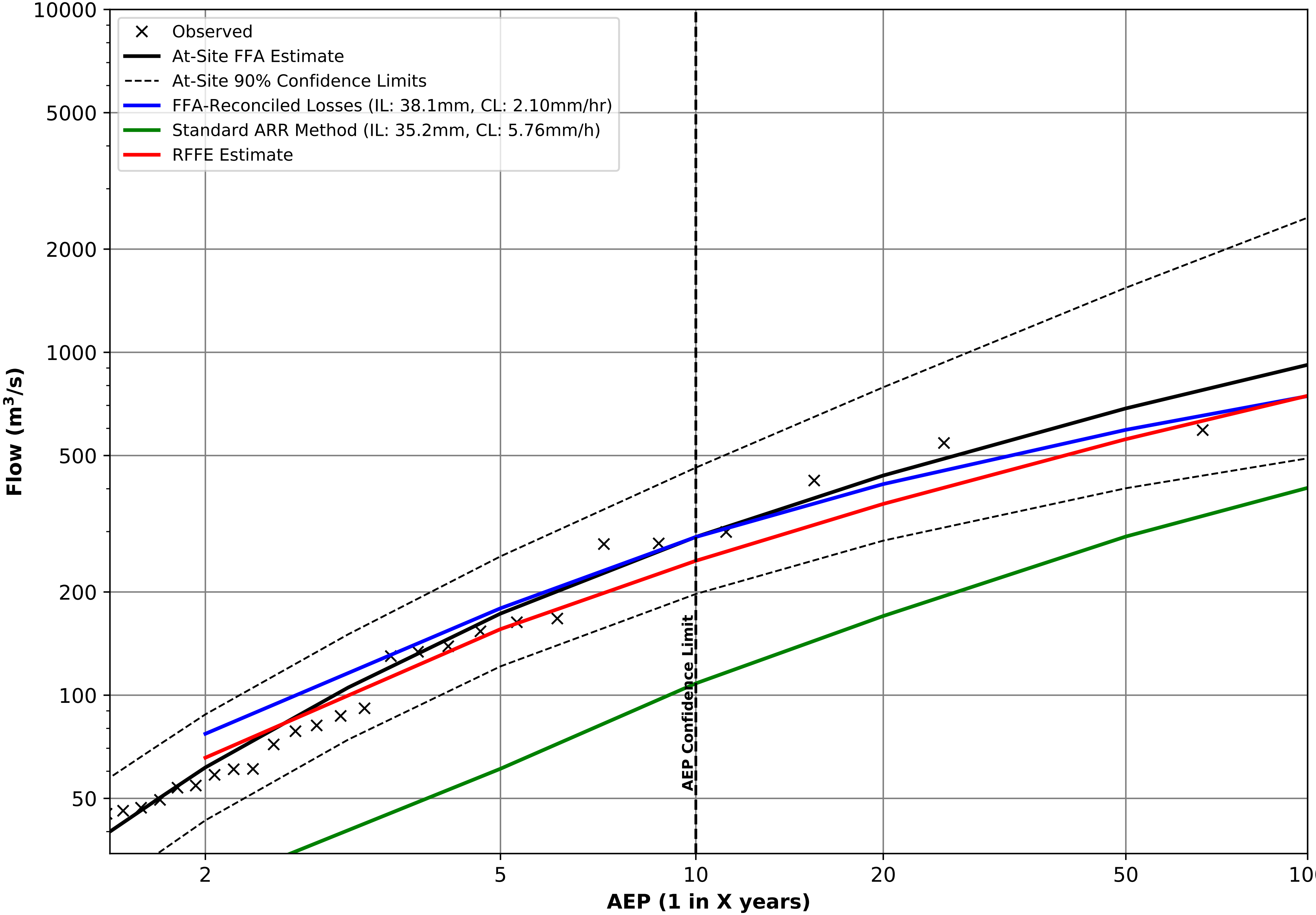
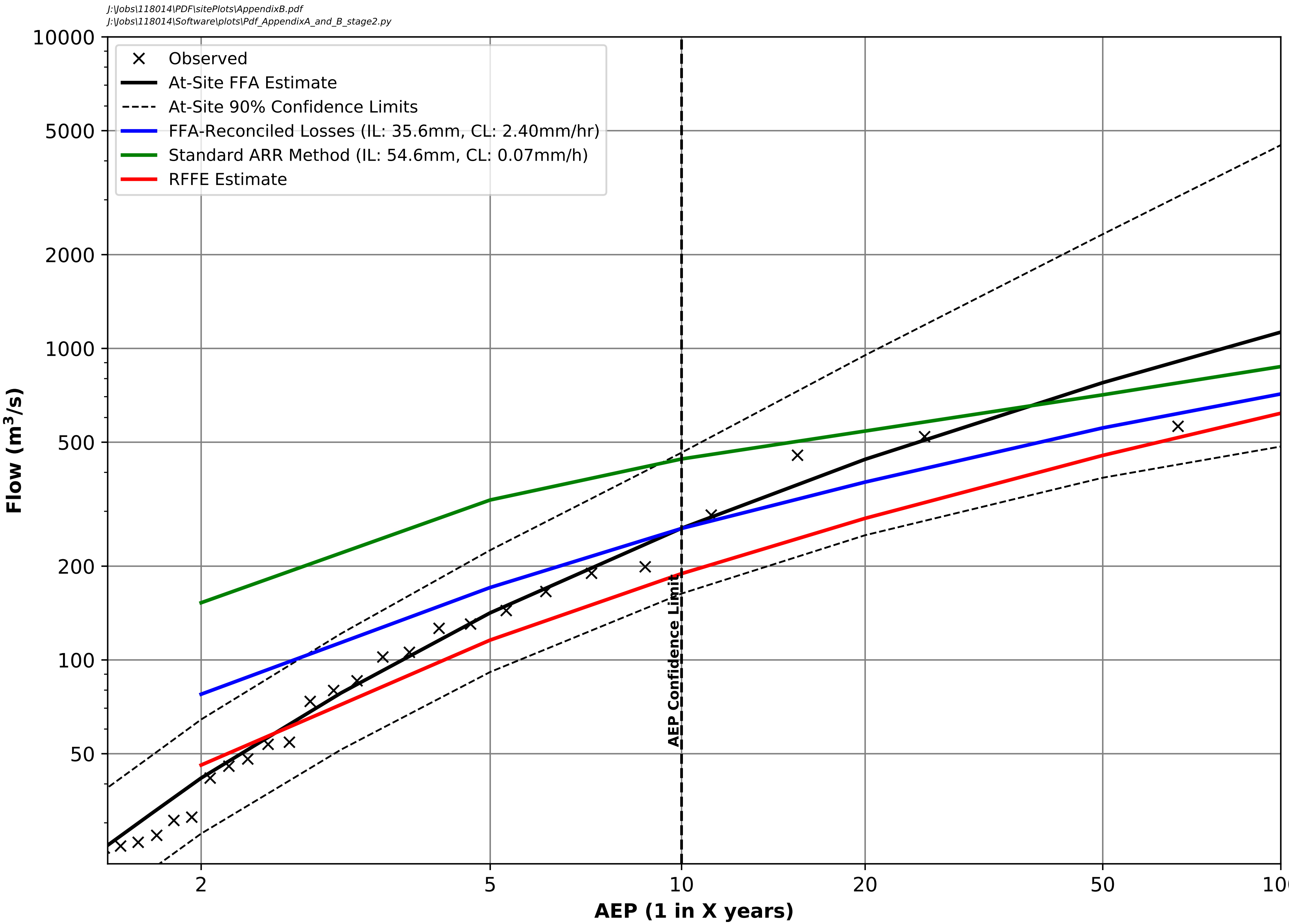


METHOD COMPARISON
BOLIVIA - 416023 [J10]

APPENDIX B149



METHOD COMPARISON
COOLATAI - 416020 [J11]

APPENDIX B150

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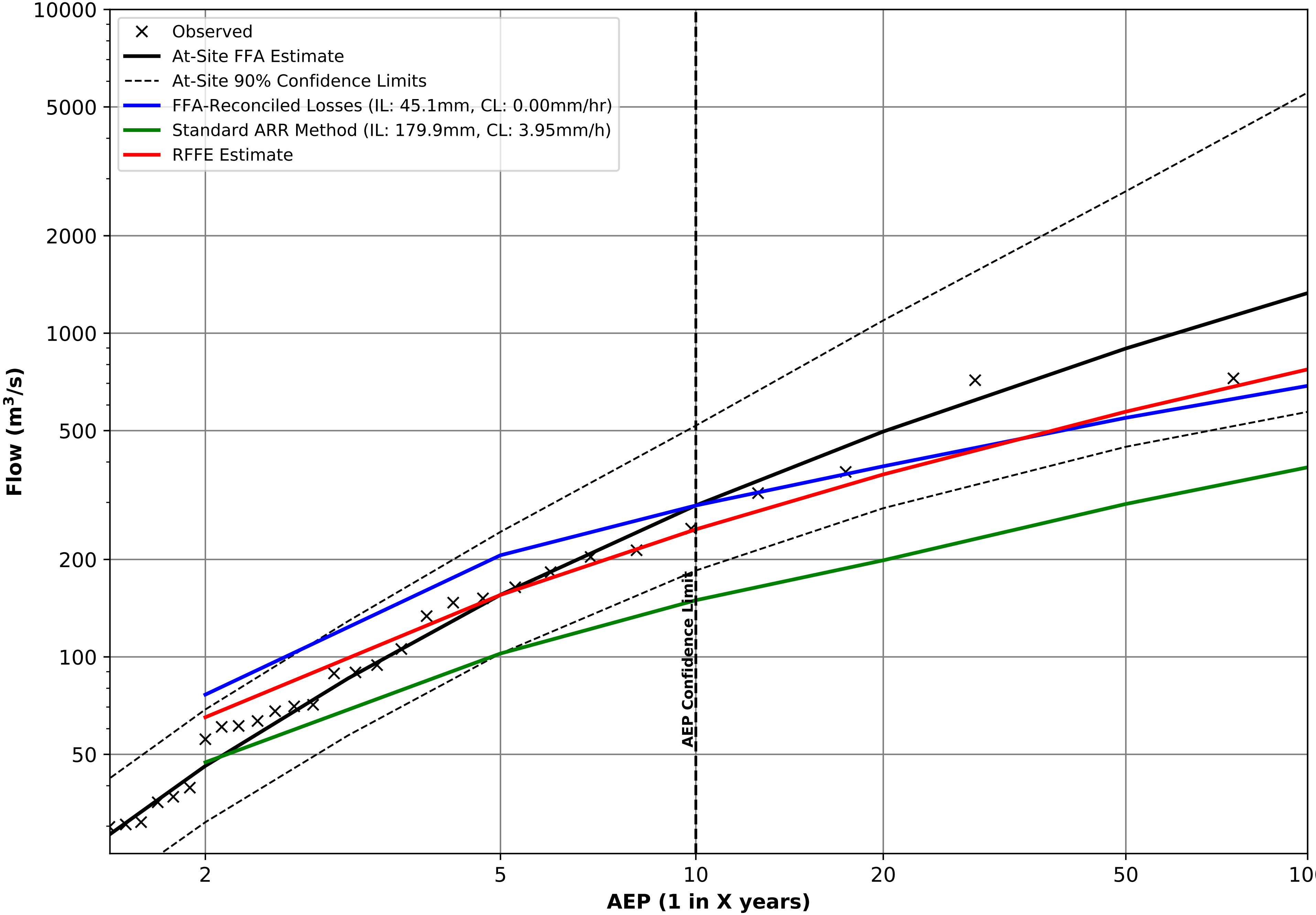

METHOD COMPARISON
LIMBRI - 419054 [J12]

APPENDIX B151

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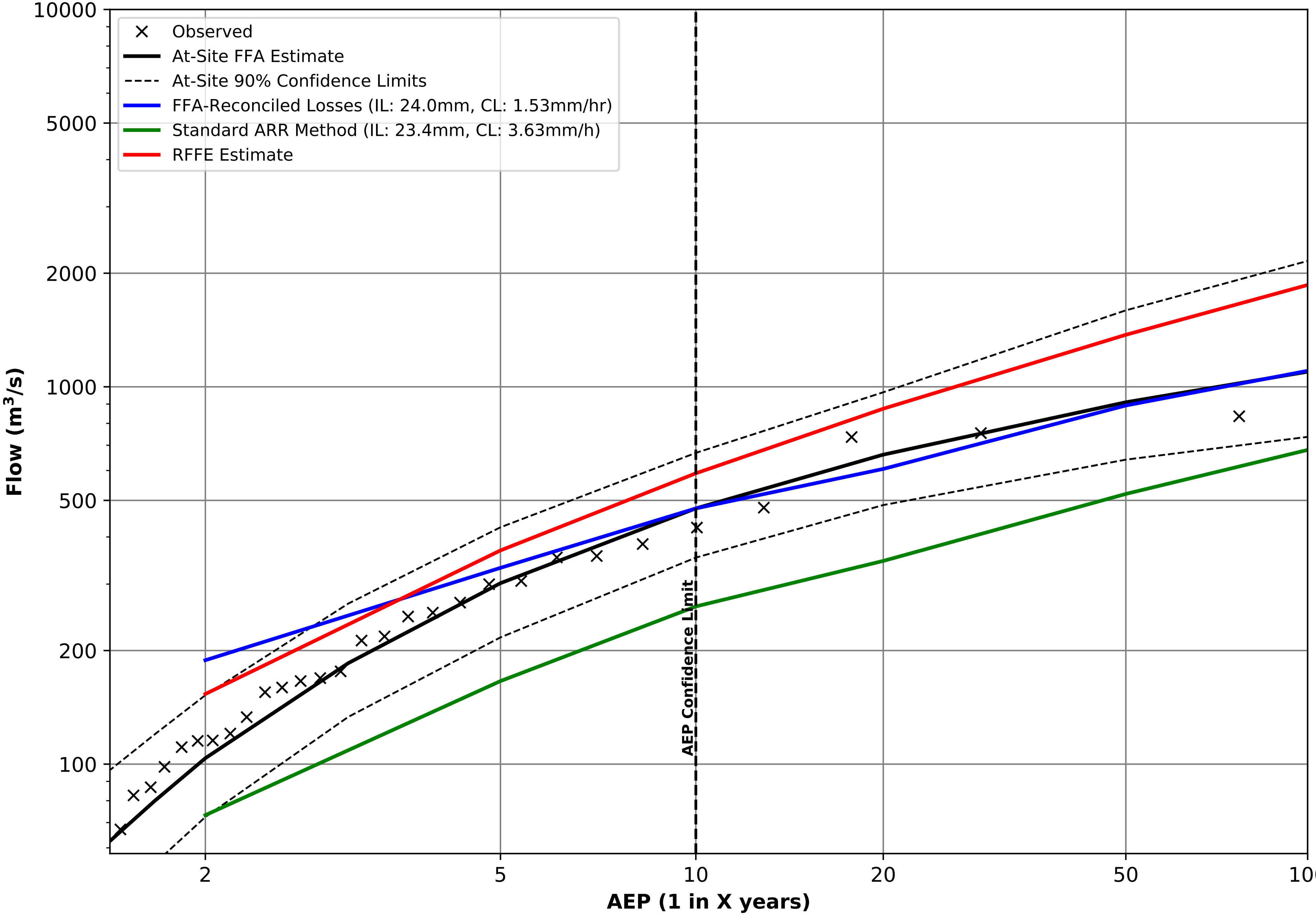

METHOD COMPARISON
MULLA CROSSING - 419016 [J13]

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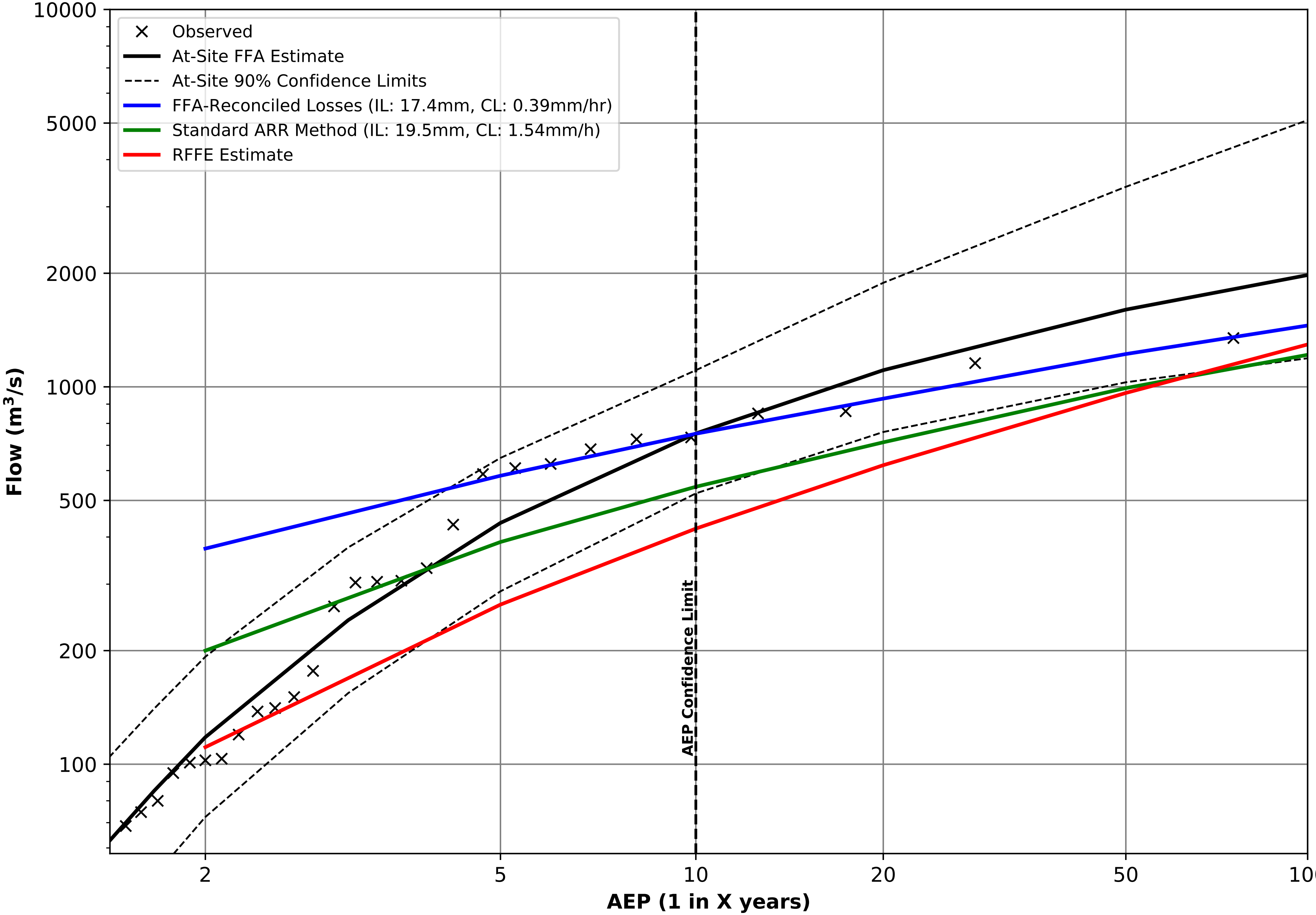
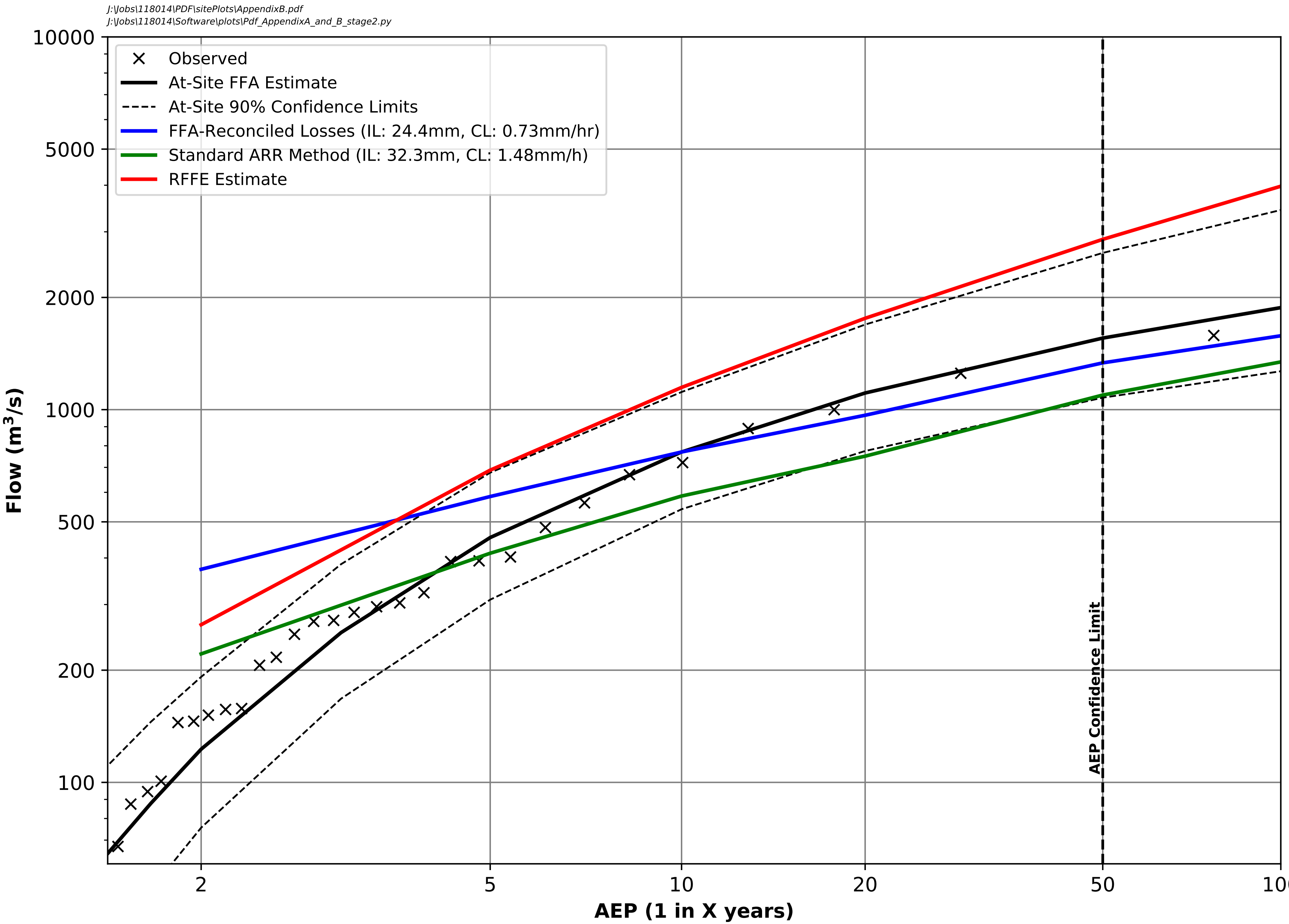
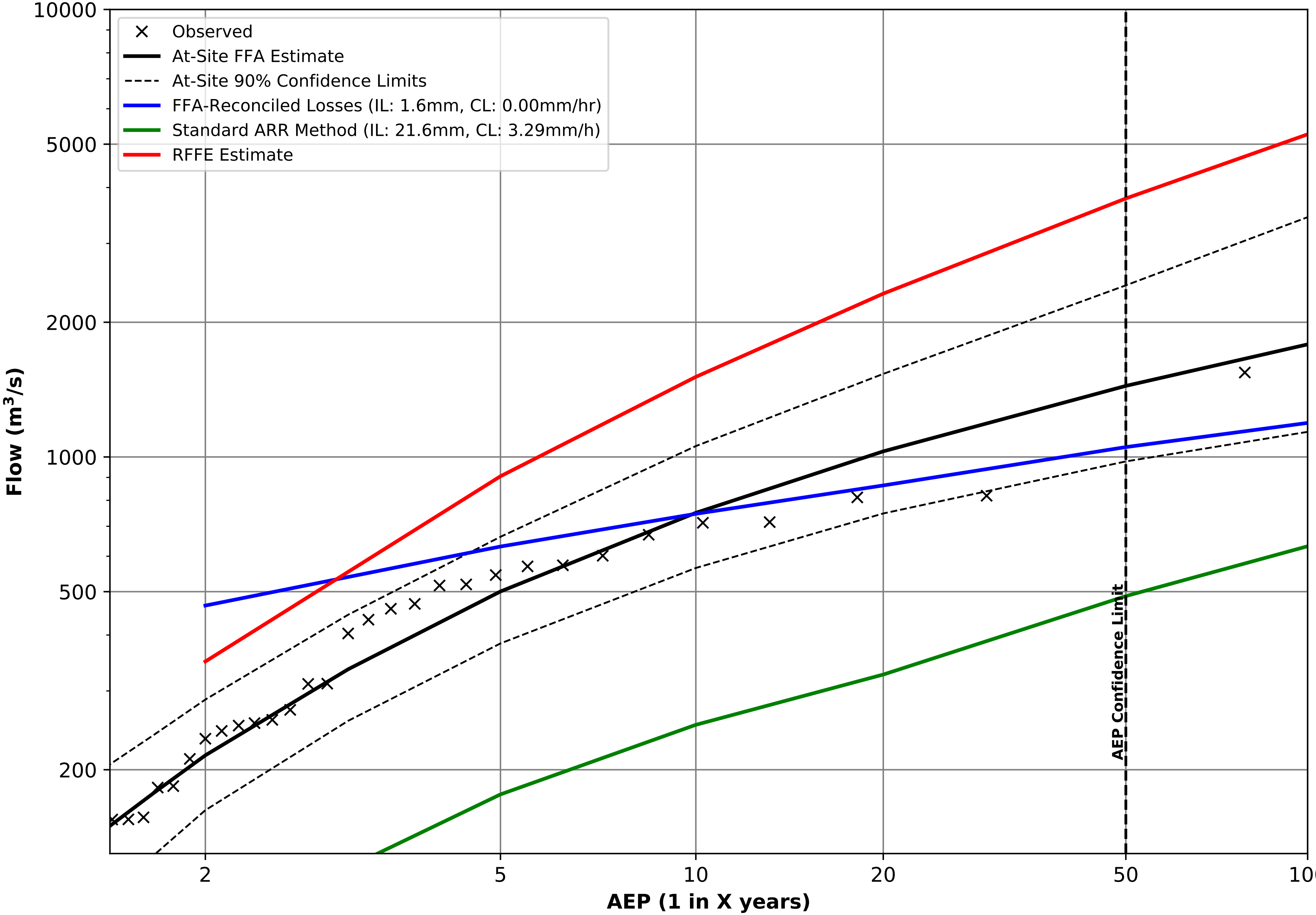


METHOD COMPARISON
BLACK SPRINGS - 419053 [J14]

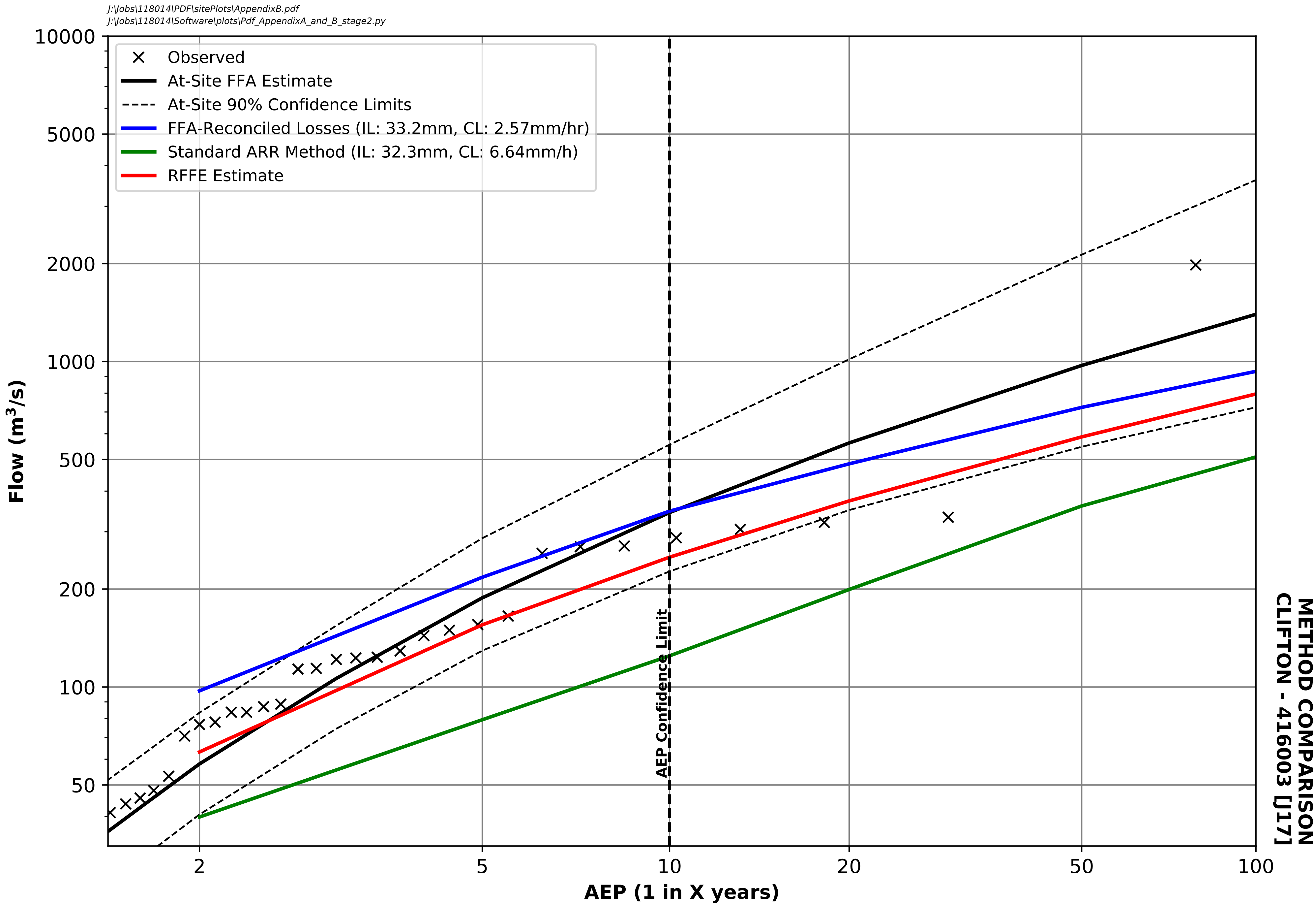
APPENDIX B153



METHOD COMPARISON
MOLROY - 418017 [J15]



METHOD COMPARISON
INVERELL (MIDDLE CK) - 416016 [J16]



APPENDIX B156

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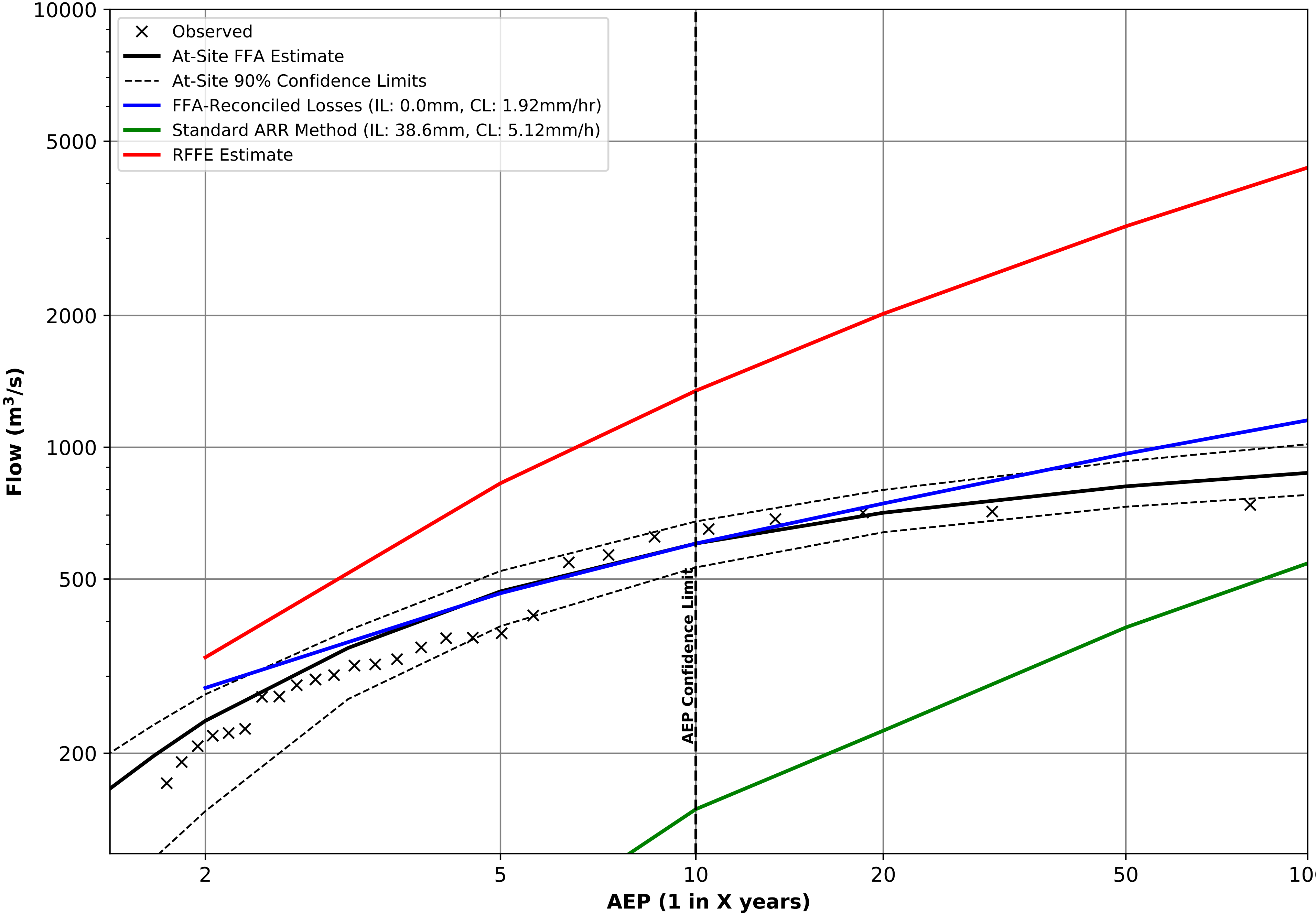
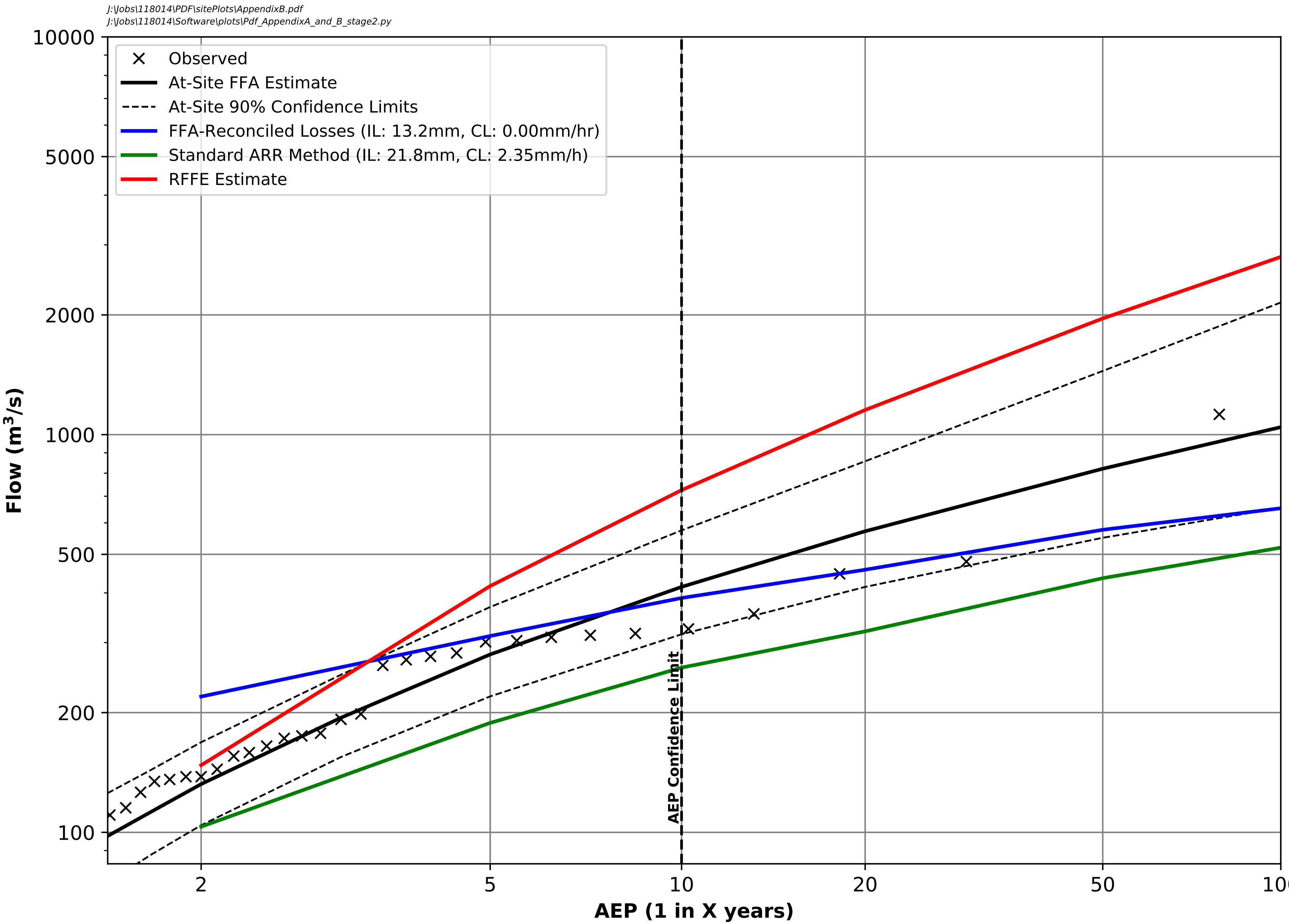


METHOD COMPARISON
HAYSTACK - 416008 [J18]



HORTON DAM SITE - 418027 [J19]

METHOD COMPARISON

APPENDIX B158

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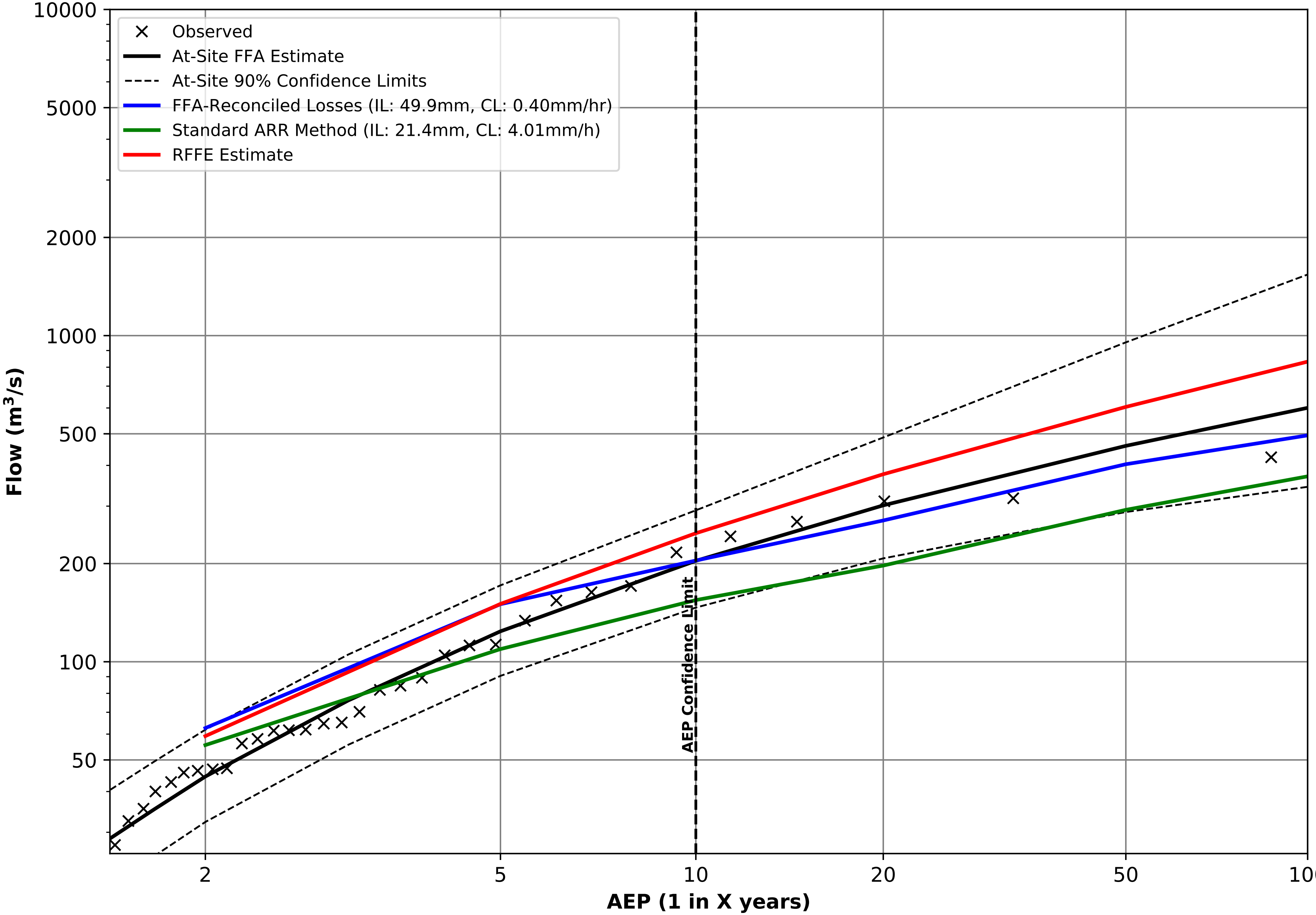

METHOD COMPARISON
KIMBERLEY - 418005 [J20]

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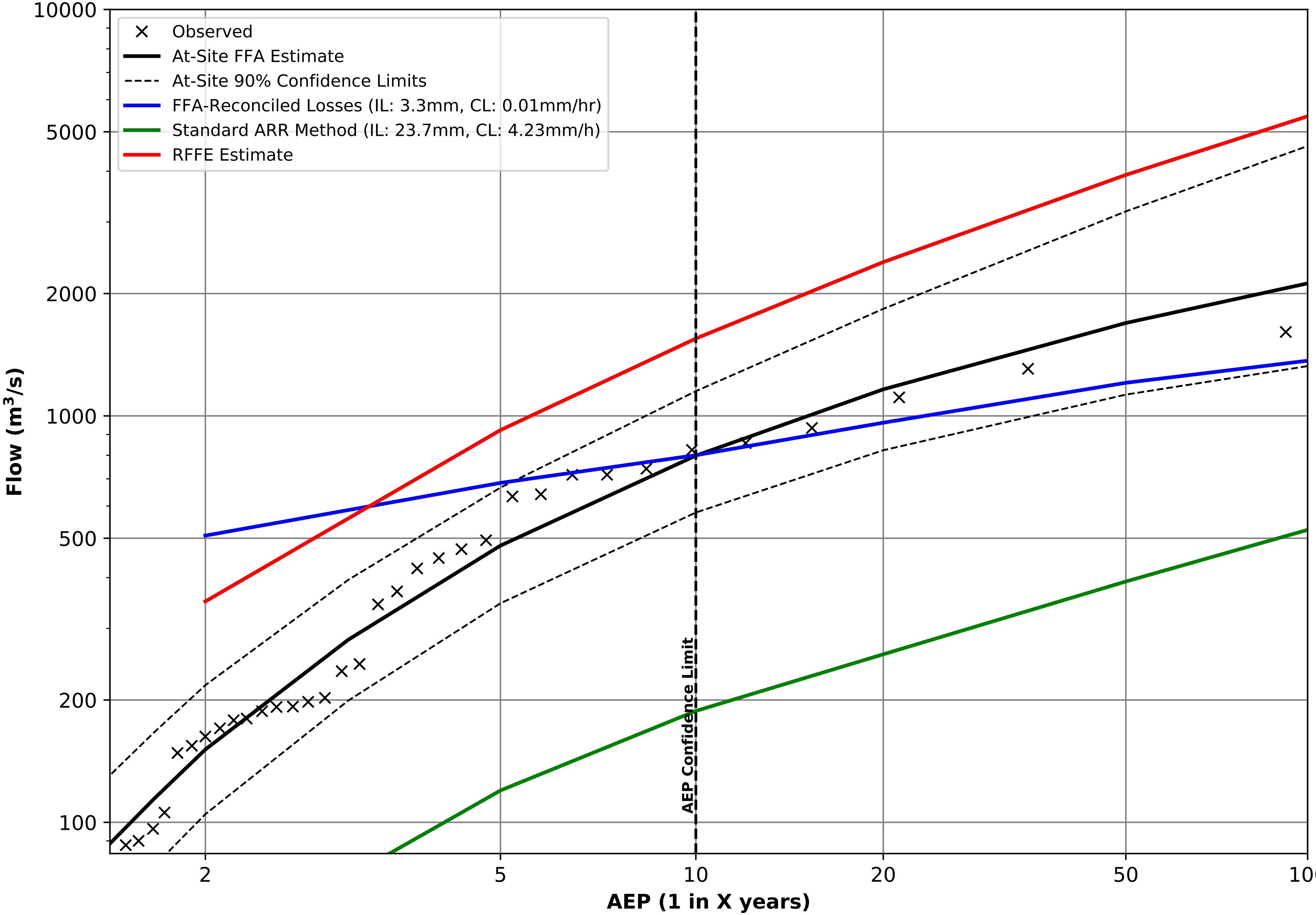

METHOD COMPARISON
YARROWYCK - 418014 [J21]

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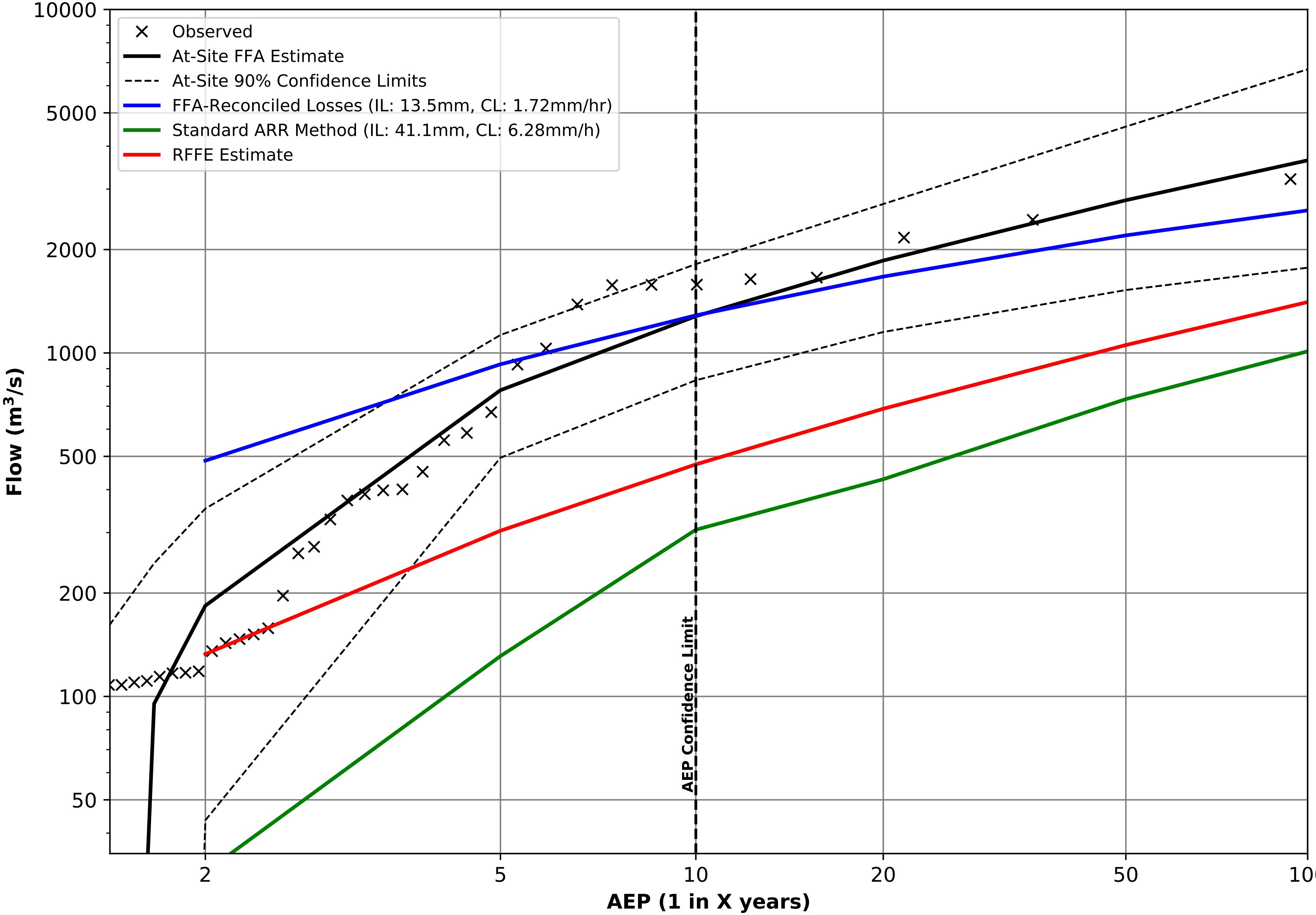

COX'S RIVER AT KELPIE POINT - COXKELPIE [COX KELPIE]

METHOD COMPARISON

APPENDIX B161

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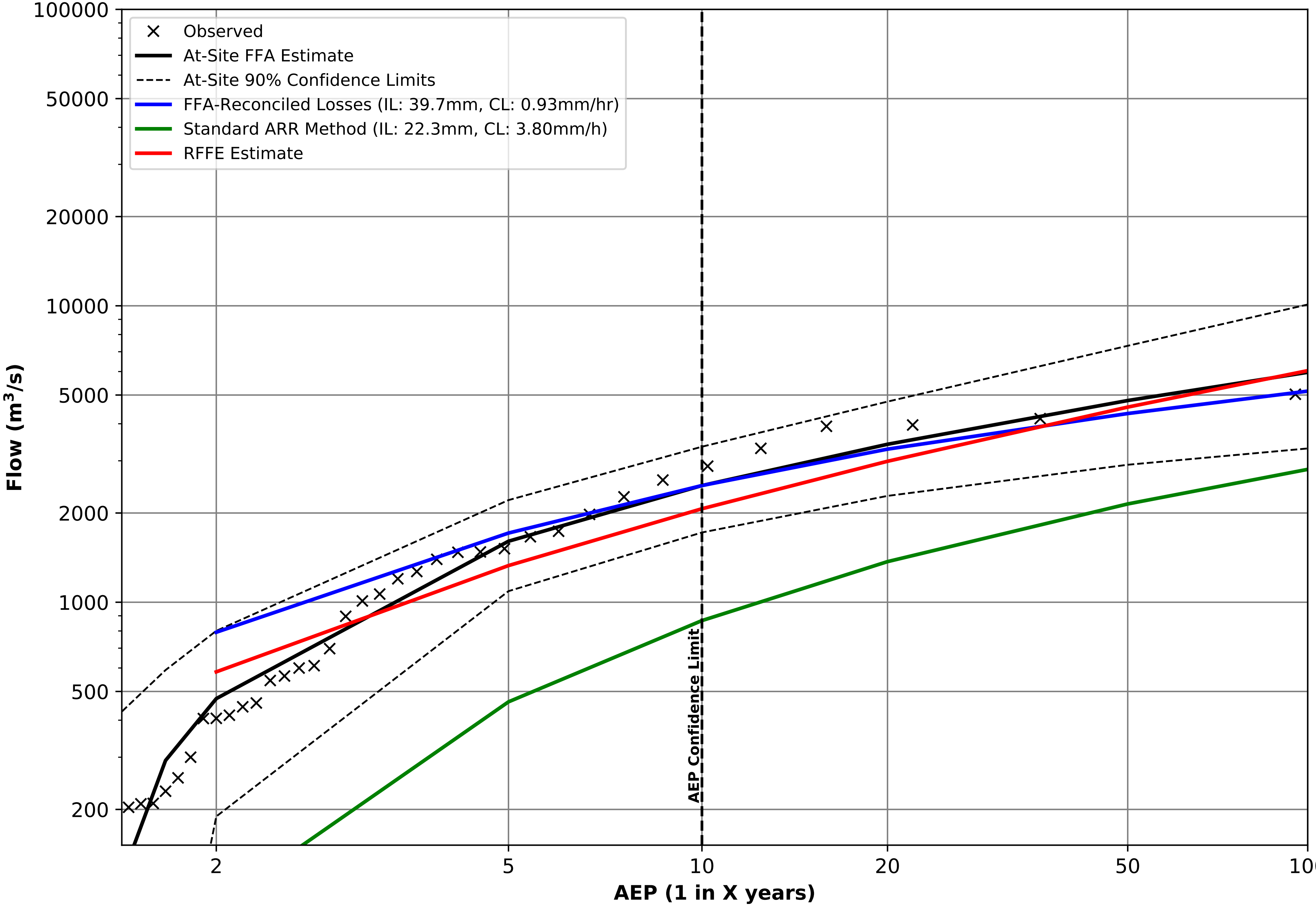

WOLLONDILLY RIVER AT JOORILAND - JOORILAND [JOORILAND]
METHOD COMPARISON

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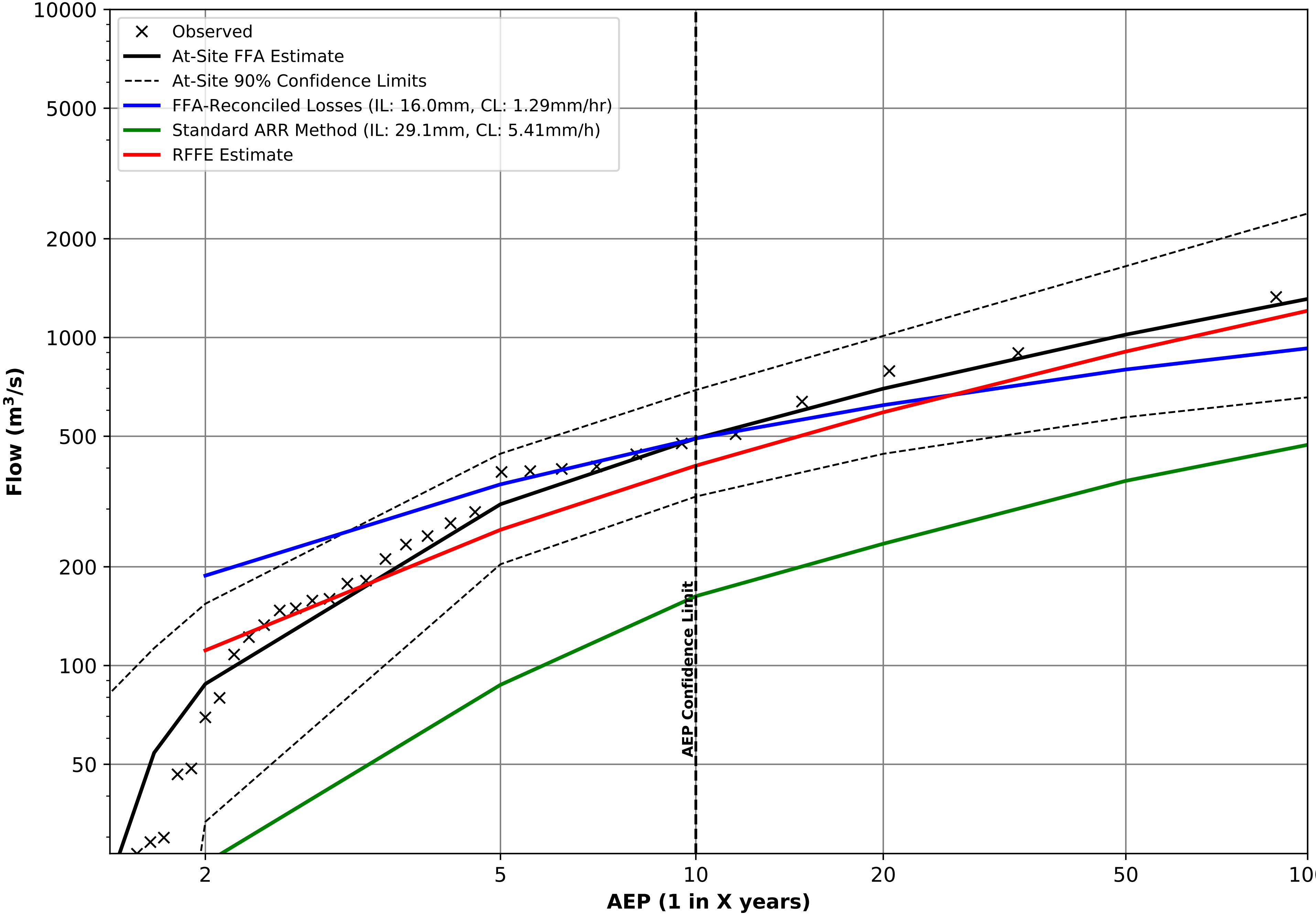
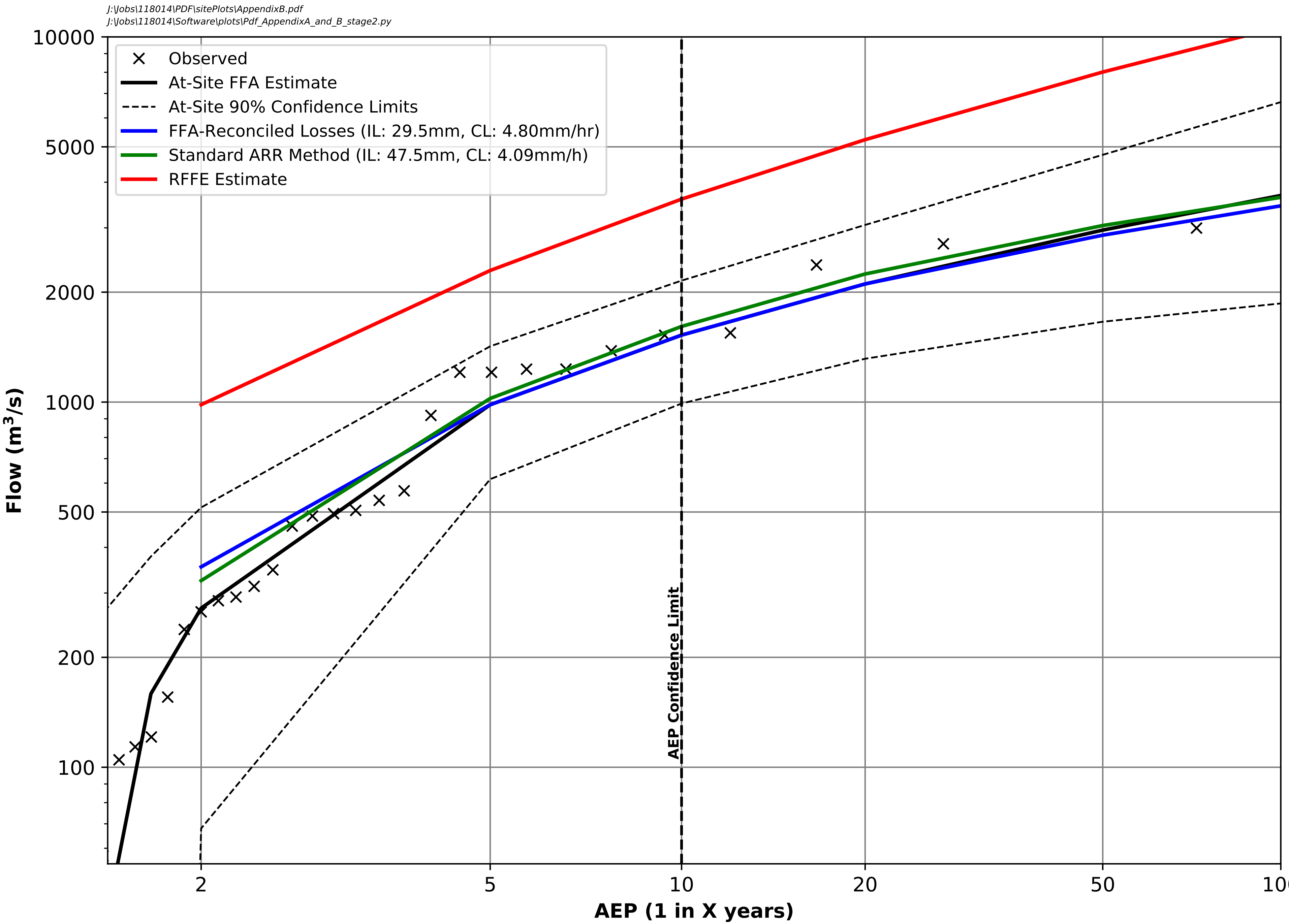


NATTAI CAUSEWAY - NATTAICAUSEWAY [NATTAI CAUSEWAY]

METHOD COMPARISON

APPENDIX B163



METHOD COMPARISON
NEPEAN RIVER AT WALLACIA - NEPEAN [NEPEAN]

APPENDIX B164

Appendix C

Table C1 Metadata and at-site flood frequency estimates for water level gauges used in this study

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m^3/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
A01	221010	Imlay Rd Br	149.6987	-37.231	37	37	31	100	153	201	252	283
A02	221002	Princes HWY	149.7138	-37.3704	48	47	171	544	812	1035	1259	1383
A03	220004	Towamba	149.6593	-37.0715	49	49	264	1169	1955	2672	3437	3874
A04	220002	Rocky Hall (Whitbys)	149.4976	-36.9435	26	26	29	130	277	512	1008	1572
A05	220001	New Buildings Br	149.561	-36.9592	28	28	166	549	960	1476	2313	3059
A06	219025	Angledale	149.8817	-36.6185	43	43	197	783	1236	1617	1990	2187
A07	219022	Candelo Dam Site	149.6855	-36.7303	48	47	46	183	351	577	969	1338
A08	219017	near Brogo	149.8106	-36.5985	53	53	72	293	524	787	1159	1443
A09	219015	near Bermagui	150.004	-36.4313	25	25	44	105	152	199	260	303
A10	219013	North Brogo	149.827	-36.534	58	44	127	566	955	1317	1711	1941
A11	219006	Tantawangalo Mountain (Dam)	149.5427	-36.7803	68	68	36	111	185	272	402	510
A12	219004	Tantawangalo School	149.625	-36.7605	32	32	93	232	359	503	718	898
A13	219003	Morans Crossing	149.6481	-36.6658	76	76	152	383	591	827	1176	1466
A14	218007	Wadbilliga	149.6926	-36.257	45	45	61	181	285	391	527	625
A15	218005	D/S Wadbilliga R Junct	149.7616	-36.1959	55	55	280	945	1480	1972	2519	2852
A16	218003	Yowrie	149.7287	-36.3048	27	26	71	144	200	259	339	402
A17	219001	Brown Mt	149.4417	-36.5967	95	79	12	44	70	95	122	138
A18	220003	Lochiel	149.8206	-36.9398	53	53	83	297	451	575	692	752
B01	222017	The Hut	149.11	-36.66	41	40	42	150	284	474	830	1195
B02	222016	The Barry Way	148.4	-36.79	44	44	13	26	40	58	93	129
B03	222009	The Falls	149.21	-36.92	45	45	316	743	1049	1331	1660	1876

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m³/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
B04	222004	Wellesley (Rowes)	149.0325	-37.1389	78	77	45	110	174	251	377	491
C02	401009	Maragle	148.1	-35.93	72	67	21	45	67	92	132	167
C03	401013	Jingellic	147.69	-35.9	47	46	42	117	199	310	510	713
C04	401015	Yambla	146.98	-35.92	46	44	26	47	64	83	110	134
C05	401016	The Square	148.1183	-36.035	36	33	2	5	7	10	15	20
C06	401017	Yarramundi	147.93	-35.7717	36	36	32	82	132	194	296	390
D01	216009	Buckenbowra No.3	150.0348	-35.7149	34	34	64	183	297	428	626	791
D02	216008	Kioloa	150.3648	-35.5435	35	32	0	1	2	3	5	7
D03	216004	Falls Creek	150.6001	-34.9684	49	49	54	173	311	496	827	1151
D04	216002	Brooman	150.2394	-35.4681	59	59	643	1701	2686	3819	5524	6956
D05	215014	Bungonia	149.9883	-34.82	38	37	49	96	125	149	175	191
D06	215008	Kadoona	149.64	-35.79	69	49	95	271	408	537	687	784
D07	215004	Hockeys	150.03	-35.15	95	31	295	455	583	723	933	1114
D08	215009	Nowra Rd	150.1183	-35.0917	10	10	348	959	1674	2690	4656	6775
E01	410160	White Hill	149.1883	-34.955	30	30	3	11	20	33	55	77
E02	410156	Book	147.5517	-35.3533	34	33	13	48	90	149	256	362
E03	410141	Michelago	149.1483	-35.705	37	35	14	56	104	167	273	369
E04	411003	Butmaroo	149.54	-35.26	41	39	27	66	105	153	233	306
E05	410114	Wyangle	148.31	-35.24	44	44	11	25	36	48	64	77
E06	410076	Jerangle Rd	149.24	-35.92	45	42	35	114	177	233	294	331
E07	410107	Mountain Ck	148.83	-35.0283	47	43	38	104	154	201	256	292
E08	410038	Butmaroo	148.25	-35.02	52	50	41	82	116	153	208	254
E09	410088	Brindabella (No.2&No.3-Cab	148.73	-35.42	60	57	55	132	208	302	458	602

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m^3/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
E10	410057	Lacmalac	148.35	-35.33	62	61	91	171	238	314	429	529
E11	410048	Ladysmith	147.51	-35.2	81	58	24	82	147	232	374	505
E12	410061	Batlow Rd	148.07	-35.33	72	72	37	83	124	171	243	305
F01	214003	Albion Park	150.7062	-34.5757	70	69	66	175	279	404	601	773
F02	213200	Wedderburn	150.8374	-34.1636	41	41	96	238	336	420	510	564
F03	213004	Parramatta Hospital	151.0013	-33.8111	26	26	125	303	515	828	1470	2208
F04	212320	Mulgoa Rd	150.7685	-33.8774	49	49	25	93	170	260	408	538
F05	212040	Pomeroy	149.54	-34.61	29	28	26	127	284	546	1128	1819
F06	212045	Island Hill	150.1967	-33.7583	38	37	51	194	405	757	1565	2571
F07	212042	Mount Walker	150.0967	-33.4983	39	39	32	76	117	164	237	299
F08	212013	Narrow Neck	150.2433	-33.73	51	44	21	59	97	142	215	280
F09	212018	Glen Davis	150.28	-33.12	49	47	42	162	264	360	466	529
F10	212011	Lithgow	150.0933	-33.5367	59	57	45	159	274	406	597	748
F11	212008	Bathurst Rd	150.08	-33.43	68	67	31	111	198	305	474	620
G01	412090	Cudal No.2	148.7383	-33.2867	21	17	26	67	91	108	124	132
G02	421106	Wiagdon	149.655	-33.2467	23	22	27	74	117	164	230	283
G03	421104	Stromlo	149.7	-33.685	25	23	13	36	60	91	142	191
G04	421101	U/S Ben Chifley Dam	149.6967	-33.6133	25	10	155	475	785	1141	1666	2094
G05	421034	Dam Site	149.9117	-33.6733	25	23	6	12	16	20	24	26
G06	421036	below Dam Site	149.94	-33.75	27	25	10	29	49	74	115	152
G07	421068	Saxa Crossing	149.0167	-32.2	28	26	7	60	114	162	207	230
G08	421066	Hill end	149.4567	-32.95	28	24	68	121	170	231	333	431
G09	412096	Kennys Ck Rd	148.7917	-34.4467	30	27	53	133	199	268	361	430
G10	421048	Obley No.2	148.5517	-32.7083	33	31	45	166	323	553	1003	1484

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m³/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
G11	412083	Tuena	149.33	-34.02	35	34	74	202	334	498	772	1025
G12	412081	near Neville	149.19	-33.8	35	35	41	103	170	261	426	594
G13	421055	Rawsonville	148.455	-32.145	39	38	75	161	209	246	281	299
G14	412063	Gunning	149.29	-34.74	43	41	78	211	349	525	826	1112
G15	421050	Molong	148.95	-33.03	45	43	63	192	353	590	1067	1596
G16	421026	Sofala	149.69	-33.08	69	52	120	411	718	1091	1673	2172
G17	412050	Narrawa North	149.17	-34.31	64	54	109	391	749	1269	2273	3333
G18	420012	Neilrex	149.3483	-31.735	24	22	40	109	197	333	622	967
G19	420010	Bearbung	148.8667	-31.6667	24	21	15	54	108	195	385	609
H01	210069	Pokolbin Site 4	151.2717	-32.8083	31	25	2	9	16	25	38	49
H02	208027	Measuring Weir	151.5033	-31.6583	32	31	119	301	451	605	811	964
H03	208026	Forbesdale (Causeway)	151.87	-32.0383	35	35	60	168	285	440	714	984
H04	207015	Mount Seaview	152.245	-31.3717	35	35	117	447	712	946	1188	1325
H05	209001	Monkerai	151.82	-32.24	36	35	178	340	440	525	617	675
H06	208024	D/S Back R Jctn	151.3433	-31.56	37	34	82	186	271	361	484	580
H07	209018	Dam Site	151.9	-32.28	40	38	307	719	969	1165	1354	1456
H08	207006	Birdwood(Filly Flat)	152.33	-31.39	48	47	326	879	1270	1609	1973	2188
H09	210084	The Rocks No.2	151.2383	-32.365	50	48	10	48	154	474	2026	5985
H10	210080	U/S Glendon Brook	151.28	-32.47	50	47	73	224	395	622	1026	1422
H11	210076	Liddell	150.98	-32.34	51	50	11	29	43	59	80	96
H12	209002	Crossing	151.98	-32.25	52	50	197	355	461	558	697	759
H13	210068	Pokolbin Site 3	151.33	-32.8	56	50	7	42	81	122	172	205
H14	210044	Middle Falbrook	151.15	-32.45	63	63	156	352	507	667	879	1039

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m³/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
		(Fal Dam Si)										
H15	210040	Wybong	150.64	-32.27	64	58	52	242	485	817	1390	1921
H16	210079	Gostwyck	151.59	-32.55	91	68	348	777	1080	1357	1683	1899
H17	208009	Barry	151.3133	-31.5817	70	70	40	105	157	209	276	323
H18	208007	Nowendoc	151.715	-31.5183	73	68	41	101	142	178	218	242
H19	208001	Bobs Crossing	151.47	-32.03	75	71	23	47	70	98	145	189
H20	210014	Rouchel Brook (The Vale)	151.05	-32.15	85	75	63	185	317	486	777	1054
H21	210022	Halton	151.51	-32.31	79	78	167	299	394	486	606	695
H22	210018	Moonam Dam Site	151.215	-31.9183	79	77	87	231	390	607	1008	1423
H23	210017	Moonan Brook	151.28	-31.94	79	73	15	34	53	78	123	169
H24	210011	Tillegra	151.6867	-32.32	88	88	234	529	762	1002	1324	1567
H25	211014	Yarramalong	151.2761	-33.2169	43	42	67	207	319	425	549	628
H26	211013	U/S Weir	151.344	-33.3482	43	43	27	79	132	199	308	407
H27	211010	U/S Wyongh R (Durren La)	151.3921	-33.2442	47	46	27	51	67	80	95	104
H28	211009	Gracemere	151.3614	-33.2692	47	46	56	178	305	457	696	901
H29	211008	Avondale	151.4702	-33.072	50	49	40	84	104	117	127	132
H30	209003	Booral	151.9571	-32.4781	51	50	569	1145	1545	1916	2366	2675
H31	208015	Landsdowne	152.514	-31.7867	50	50	158	286	365	432	506	553
H32	207014	Avenel	152.7415	-31.331	35	35	546	1102	1446	1735	2042	2229
H33	207013	D/S Bunnoo R Junction	152.4489	-31.4794	44	44	301	652	929	1214	1600	1895
I01	206034	Abermala	151.7067	-30.7	35	34	23	61	90	118	152	175

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m³/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
I02	204067	Fine Flower	152.6533	-29.4033	36	12	446	727	962	1227	1638	2002
I03	206001	Jeogla	152.1617	-30.59	41	40	47	101	154	221	335	445
I04	204033	Billyrimba	152.25	-29.195	41	53	69	198	329	489	747	976
I05	204030	Aberfoyle	152.01	-30.26	42	40	29	55	74	92	115	131
I06	204056	Gibrattar Range	152.45	-29.49	44	44	91	227	370	557	888	1216
I07	204008	Ebor	152.345	-30.405	46	44	30	66	97	132	184	228
I08	206025	near Dangar Falls	151.71	-30.68	47	47	43	201	369	559	815	1003
I09	204037	Clouds Ck	152.63	-30.09	48	48	43	108	149	181	213	230
I10	204034	Newton Boyd	152.2117	-29.7633	48	47	69	177	298	466	783	1120
I11	203005	Wiangaree	152.9667	-28.5067	48	46	449	1086	1565	2022	2580	2961
I12	204043	Bonalbo	152.6733	-28.7367	59	57	26	65	102	147	221	288
I13	206018	Apsley Falls	151.7683	-31.0517	67	62	98	268	419	584	818	1002
I14	206014	Coninside	152.0267	-30.4783	65	65	93	218	327	447	623	768
I15	206009	Tia	151.83	-31.19	65	65	43	108	180	278	460	649
I16	204036	Sandy Hill(below Snake Cre)	152.22	-28.93	67	67	88	234	386	582	920	1244
I17	205014	Gleniffer Br	152.8814	-30.3863	26	25	191	285	335	375	416	441
I18	205007	Woolgoolga	153.1641	-30.117	24	23	16	50	91	151	269	397
I19	205006	Bowraville	152.856	-30.6405	41	36	361	761	1024	1254	1512	1675
I20	205002	Thora	152.7809	-30.4259	37	37	250	571	816	1059	1369	1592
I21	204026	Bobo Nursery	152.848	-30.2495	33	31	199	337	441	547	695	813
I22	204025	Karangi	153.0333	-30.2528	50	49	206	391	539	696	919	1101
I23	204017	Dorrigo No.2 & No.3	152.7146	-30.3057	48	48	147	309	437	567	743	877
I24	203014	Etham	153.3955	-28.7561	62	62	200	344	441	532	646	727

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m^3/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
I25	203012	Binna Burra	153.4981	-28.7059	42	41	93	193	277	369	503	615
I26	203010	Rock Valley	153.164	-28.7365	52	52	375	580	740	913	1167	1382
I27	203002	Repentance	153.4138	-28.6388	43	42	215	369	473	570	691	778
I28	202001	Durrumbul (Sherrys Crossing)	153.458	-28.5315	48	47	86	179	253	329	434	516
I29	201005	Boat Harbour No.20.55 cm	153.336	-28.3096	62	42	322	598	762	897	1039	1125
I30	201001	Eungella	153.2931	-28.3512	62	62	422	845	1113	1344	1596	1754
J01	419044	Damsite	150.3	-30.5333	25	22	36	108	188	293	478	658
J02	419047	Woodsreef	150.7267	-30.41	28	28	51	219	377	533	719	837
J03	418034	Black Mountain	151.64	-30.3	31	31	2	9	18	33	68	111
J04	204031	Shannon Vale	151.845	-29.7217	35	34	48	163	290	452	719	961
J05	419076	Old Warrah	150.6433	-31.66	37	36	34	162	279	390	510	579
J06	419035	Timbumburi	150.915	-31.2733	38	37	92	272	402	514	633	702
J07	419010	Woolbrook	151.35	-30.97	40	40	96	249	405	602	935	1251
J08	419029	Ukolan	150.83	-30.71	41	39	12	51	102	176	315	456
J09	418025	Bingara	150.57	-29.94	41	40	21	106	206	330	518	670
J10	416023	Bolivia	151.92	-29.29	41	40	62	173	289	437	686	919
J11	416020	Coolatai	150.76	-29.23	41	40	42	142	265	441	776	1128
J12	419054	Limbri	151.17	-31.04	45	45	46	156	294	497	897	1330
J13	419016	Mulla Crossing	151.13	-31.06	46	46	104	302	476	661	910	1096
J14	419053	Black Springs	150.65	-30.42	47	45	118	436	753	1107	1602	1978
J15	418017	Molroy	150.58	-29.8	55	46	123	454	770	1108	1556	1878
J16	416016	Inverell (Middle Ck)	151.13	-29.79	48	47	215	500	750	1029	1442	1785

Station	Station Number	Station Name	Station Longitude	Station Latitude	Length of record (years)	AMS	Peak Flow (m^3/s)					
							50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
J17	416003	Clifton	151.72	-29.03	98	47	58	188	344	562	973	1397
J18	416008	Haystack	151.5703	-29.351	49	48	237	469	603	709	814	874
J19	418027	Horton Dam Site	150.43	-30.21	49	47	132	280	414	572	821	1044
J20	418005	Kimberley	151.11	-29.92	90	52	45	124	204	302	459	601
J21	418014	Yarrowyck	151.36	-30.47	64	55	151	480	799	1162	1693	2119
JOORILAND	JOORILAND	Wollondilly River at Jooriland	150.254	-34.2224	57	57	473	1606	2475	3411	4791	5966
NATTAI CAUSEWAY	NATTAICAUSEWAY	Nattai Causeway	150.6243	-34.2224	42	42	88	310	492	698	1021	1311
NEPEAN	NEPEAN	Nepean River at Wallacia	150.4177	-34.1363	43	43	273	983	1525	2106	2958	3680
COX KELPIE	COXKELPIE	Cox River at Kelpie Point	150.2454	-33.8607	56	56	184	779	1279	1858	2784	3637

Table C2 Metadata and flood frequency estimates associated with the application of the standard ARR 2016 method for catchments investigated in this study

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
A01	149.687	-37.176	70	0.74	34	89	131	178	257	313
A02	149.612	-37.242	477	0.77	100	303	473	692	1009	1310
A03	149.537	-36.983	769	0.53	136	430	662	979	1566	2047
A04	149.434	-39.957	79	0.66	35	88	128	175	252	305
A05	149.480	-36.921	274	0.5	103	273	396	547	792	987
A06	149.673	-36.507	725	0.83	68	260	444	701	1218	1666
A07	149.543	-36.7651	201	0.94	54	160	241	345	534	682
A08	149.714	-36.594	160	0.68	45	147	230	334	497	642
A09	149.98	-36.449	35	0.45	30	69	96	127	178	213
A10	149.625	-36.466	455	0.92	16	125	303	550	904	1205
A11	149.4858	-36.74	84	0.74	35	94	137	190	266	332
A12	149.512	-36.767	160	0.74	52	150	222	312	462	582
A13	149.520	-36.601	316	0.74	23	134	282	463	713	923
A14	146.629	-36.286	127	0.58	25	79	130	194	298	389
A15	149.613	-36.228	920	0.46	58	236	407	651	1146	1580
A16	149.706	-36.353	102	0.57	33	105	164	237	343	440
A17	149.410	-36.594	15	0.74	7	19	28	39	55	65
A18	149.765	-36.915	106	0.55	49	144	214	296	431	525
B1	149.282	-36.587	326	0.7	20	74	126	195	309	393
B2	148.321	-36.7098	157	0.91	4	14	26	46	81	107
B3	149.3477	-36.789	558	0.81	71	219	342	513	810	1050
B4	149.033	-37.1389	616	0.66	24	120	222	371	611	798
C2	148.206	-35.869	219	0.79	19	42	69	102	150	186
C3	147.696	-35.777	404	0.68	21	45	79	126	203	260

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
C4	146.939	-35.895	285	0.28	19	42	78	111	181	234
C5	148.1573	-36.0699	51	0.73	6	15	24	35	52	64
C6	147.876	-35.7204	198	0.53	17	35	60	94	148	186
D1	149.972	-35.672	165	0.58	37	135	215	312	480	620
D2	150.3658	-35.544	2	0.09	5	9	12	15	19	22
D3	150.540	-34.9901	103	0.59	85	186	264	344	474	554
D4	150.1908	-35.3641	861	0.42	89	320	568	868	1394	1796
D5	149.8999	-34.8603	163	0.72	54	102	141	183	254	304
D6	149.606	-35.8964	283	0.73	15	75	131	211	371	506
D7	150.061	-35.235	168	0.76	30	87	137	205	302	369
D8	150.1765	-35.1513	208	0.59	62	166	254	354	507	611
E1	149.1897	-34.9743	9	0.71	2	5	8	12	18	23
E2	147.576	-35.434	146	0.79	13	33	59	90	140	177
E3	149.219	-35.729	191	0.5	10	30	57	93	156	206
E4	149.543	-35.319	62	0.83	10	25	41	61	93	120
E5	148.337	-35.225	21	0.64	6	14	21	29	41	51
E6	149.3009	-35.867	209	0.56	20	50	78	112	165	216
E7	148.8028	-35.1292	187	0.84	33	74	126	188	279	354
E8	148.4374	-35.1419	393	1.1	53	106	176	263	396	507
E9	148.698	-35.544	432	0.68	66	151	228	311	456	589
E10	148.4822	-35.4221	668	0.61	119	230	353	505	734	920
E11	147.4948	-35.3485	548	0.71	21	55	102	168	287	375
E12	148.0983	-35.4388	148	1.02	16	35	59	89	132	167
F1	150.6764	-34.5744	45	0.41	56	125	179	237	342	412
F2	150.8639	-34.2033	86	0.54	109	221	297	383	507	588

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km²)	Shape Factor	Peak Flow (m³/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
F3	150.9758	-33.7763	104	0.44	103	178	236	305	409	486
F4	150.7522	-33.9607	90	0.99	36	84	124	173	242	295
F5	149.5013	-34.5605	94	0.67	7	23	40	62	97	125
F6	150.1394	-33.5458	968	0.78	14	61	146	208	364	509
F7	150.1621	-33.4729	70	0.8	4	14	29	50	77	97
F8	150.2697	-33.7163	26	0.56	6	18	32	45	69	85
F9	150.1218	-33.0432	965	0.55	6	27	60	96	194	294
F10	150.0895	-33.4309	409	0.58	8	31	73	121	213	289
F11	150.058	-33.3841	203	0.38	4	17	41	82	152	207
G1	148.8696	-33.2446	264	0.81	26	61	101	146	226	290
G2	149.7314	-33.2398	95	0.73	7	16	34	41	65	92
G3	149.7664	-33.7673	96	1.13	9	26	51	61	92	119
G4	149.6569	-33.7622	928	0.56	25	75	153	204	310	403
G5	149.8958	-33.6645	16	0.45	4	10	20	21	28	35
G6	149.9039	-33.8205	113	0.8	9	37	65	99	146	184
G7	149.0903	-32.3018	372	0.69	83	177	284	397	550	667
G8	149.5052	-32.988	126	0.55	30	66	98	123	169	208
G9	148.8852	-34.526	338	0.67	17	38	73	120	214	288
G10	148.527	-32.904	577	0.91	72	173	265	364	534	671
G11	149.374	-34.1362	326	0.75	18	29	67	104	181	234
G12	149.230	-33.770	149	0.41	19	44	72	105	161	201
G13	148.6363	-32.0151	676	0.86	45	131	213	309	482	644
G14	149.425	-34.7784	577	0.54	44	103	163	238	356	463
G15	149.0503	-33.13	376	0.75	25	68	107	144	231	314
G16	149.8947	-33.2039	885	0.79	13	44	113	145	241	325

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
G17	149.3553	-34.3856	762	0.69	28	65	98	155	282	376
G18	149.5378	-31.7824	401	0.93	50	145	216	300	437	550
G19	148.9805	-31.5278	433	0.91	55	158	242	352	522	664
H1	151.2594	-32.8097	5	0.51	3	9	12	17	24	29
H2	151.3489	-31.599	718	0.6	40	102	169	241	388	517
H3	151.5634	-31.518	548	2.77	4	17	44	89	185	281
H4	152.169	-31.2672	356	0.72	20	96	196	315	485	626
H5	151.7536	-32.17	203	0.7	97	203	292	394	549	665
H6	151.2612	-31.559	283	0.46	52	112	172	239	348	429
H7	151.7842	-32.12	293	0.83	105	255	371	495	674	819
H8	152.324	-31.257	335	0.81	63	252	420	596	842	1031
H9	151.2861	-32.2702	228	0.76	61	144	217	292	402	489
H10	151.2824	-32.427	73	0.57	53	97	131	166	234	265
H11	150.984	-32.3205	13	0.61	8	15	21	28	38	46
H12	152.0549	-32.254	158	0.56	119	242	330	429	564	668
H13	151.287	-32.8104	25	0.85	11	31	48	66	96	117
H14	151.2378	-32.316	449	0.8	100	260	384	510	695	845
H15	150.6256	-32.0533	669	0.93	28	112	211	326	510	666
H16	151.4923	-32.314	972	0.89	155	373	594	795	1164	1475
H17	151.233	-31.5894	152	0.62	36	81	118	161	229	279
H18	151.655	-31.43	221	0.77	4	17	36	57	110	166
H19	151.4414	-32.03	20	0.6	12	24	34	47	66	78
H20	151.1867	-32.1232	3400	0.66	56	170	267	365	516	633
H21	151.476	-32.193	190	0.97	54	122	188	259	375	465
H22	151.3191	-31.8334	742	0.5	38	106	192	262	427	569

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
H23	151.3704	-31.974	105	0.91	22	53	84	122	178	219
H24	151.5869	-32.229	203	0.97	65	146	218	300	430	532
H25	151.2542	-33.218	181	0.15	63	160	265	392	565	704
H26	151.2846	-33.301	90	0.8	48	111	171	243	348	434
H27	151.3609	-33.1803	94	0.79	44	108	170	239	344	427
H28	151.3525	-33.2813	238	0.1	67	177	289	438	634	791
H29	151.4841	-33.025	66	0.66	42	109	165	226	307	377
H30	151.920	-32.273	975	0.74	292	741	1092	1457	1996	2435
H31	152.4659	-31.7104	100	0.96	75	175	249	337	460	548
H32	152.6021	-31.232	508	0.76	328	714	992	1276	1655	1951
H33	152.312	-31.5472	502	0.67	60	257	453	673	1007	1281
I01	151.6482	-30.767	119	0.85	35	66	93	123	172	211
I02	152.719	-29.306	341	0.71	212	415	605	787	1030	1214
I03	152.2788	-30.524	166	1.04	57	154	236	333	478	596
I04	152.1584	-29.4338	987	0.89	6	47	119	213	430	670
I05	151.8276	-30.1904	211	1.32	34	68	98	131	187	240
I06	152.3596	-29.5256	11	0.9	6	35	77	126	230	315
I07	152.3822	-30.414	34	0.64	26	68	106	137	196	238
I08	151.5604	-30.68	652	0.56	63	140	217	314	473	607
I09	152.5712	-30.1105	64	0.76	27	82	140	216	319	398
I10	152.05	-29.8712	400	0.98	9	33	63	114	220	314
I11	152.8984	-28.4117	714	0.47	242	690	1103	1539	2134	2595
I12	152.7015	-28.6829	47	0.96	30	74	108	144	197	235
I13	151.6335	-30.996	853	0.48	99	214	325	450	661	835
I14	151.936	-30.352	382.9015	0.84	57	110	163	229	341	433

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
I15	151.7567	-31.2597	265	0.64	8	29	58	86	169	240
I16	152.1339	-29.0082	243	0.77	7	29	64	119	228	321
I17	152.8894	-30.3466	50	0.63	92	182	247	319	436	519
I18	153.1538	-30.1219	17	0.28	25	58	85	107	140	170
I19	152.7235	-30.610	429	0.63	371	756	1040	1374	1815	2131
I20	152.5662	-30.4537	447	0.98	271	637	939	1279	1751	2108
I21	152.8508	-30.2853	80	0.45	119	257	352	473	651	775
I22	152.9701	-30.2888	137	0.62	211	440	598	796	1081	1294
I23	152.6981	-30.3529	76	0.63	123	254	357	460	632	755
I24	153.4689	-28.6805	224	0.74	352	653	843	1048	1356	1542
I25	153.5379	-28.686	40	0.71	29	161	220	260	332	385
I26	153.1317	-28.6067	181	1.1	170	375	517	657	841	993
I27	153.3871	-28.5859	63	0.81	151	274	350	446	579	676
I28	153.416	-28.5013	37	0.87	98	177	239	291	388	453
I29	153.2822	-28.2836	115	0.56	228	458	616	796	1070	1266
I30	153.192	-28.3572	216	0.68	381	762	1008	1322	1761	2084
J01	150.3295	-30.4589	169	0.67	92	168	223	283	384	457
J02	150.8387	-30.3289	555	0.6	154	295	416	544	766	947
J03	151.6496	-30.2758	14	0.75	8	16	24	30	41	50
J04	151.778	-29.9142	363	1.17	55	114	169	212	350	445
J05	150.6751	-31.7439	164	0.76	37	90	141	196	277	344
J06	150.9413	-31.4077	456	0.71	116	239	339	442	607	732
J07	151.4993	-31.1795	836	0.94	45	106	195	245	409	557
J08	150.9706	-30.7847	376	0.81	84	162	229	300	435	540
J09	15.5965	-30.0204	158	0.74	104	165	229	283	375	448

Station	Catchment Centroid Longitude	Catchment Centroid Latitude	Catchment Area (km^2)	Shape Factor	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
J10	151.9222	-29.3993	541	0.52	27	61	108	170	290	402
J11	150.7902	-29.3699	385	0.81	153	326	442	543	710	874
J12	151.3266	-31.1362	400	0.92	47	102	150	199	297	385
J13	151.2803	-31.1313	900	0.55	73	166	262	346	520	680
J14	150.5119	-30.403	772	0.48	200	388	544	713	993	1216
J15	150.7942	-29.7524	870	0.72	221	412	586	750	1094	1343
J16	151.3571	-29.8684	755	0.86	85	176	252	326	489	632
J17	151.9338	-29.01	559	0.88	40	79	125	199	360	509
J18	151.5703	-29.351	912	0.78	23	75	149	225	388	543
J19	150.3248	-30.2988	206	0.99	103	188	260	320	436	520
J20	151.2527	-29.959	250	0.91	56	109	155	197	292	370
J21	151.4778	-30.5073	835	0.42	46	120	188	259	291	524
Cox Kelpie	150.1361	-33.6474	1469	0.67	31	131	306	429	734	1011
Jooriland	149.9167	-34.5657	4732	0.71	95	461	867	1371	2146	2807
Nattai Causeway	150.3832	-34.3219	458	1.16	25	87	163	235	366	471
Nepean	150.6611	-34.3485	1247	0.92	324	1023	1611	2243	3044	3636

Table C3 Metadata and design flood estimates associated with the FFA-Reconciled Losses method for catchments investigated in this study with good quality At-site FFA fits

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
A01	Good	1080	50	3.3	40	100	149	200	277	334
A03	Good	1080	18	0.01	887	1406	1788	2184	2871	3358
A05	Good	2880	49	0.002	356	613	783	951	1212	1414
A06	Good	2880	50	1.7	314	785	1158	1598	2203	2681
A07	Good	2880	49	3.1	90	240	349	475	678	827
A08	Good	2880	49	0.01	215	386	501	623	805	950
A09	Good	540	25	0.007	71	115	147	180	231	266
A10	Good	2880	49	1.2	327	686	954	1240	1617	1927
A11	Good	2880	50	3.03	52	130	185	242	323	388
A12	Good	2880	49	2.01	118	260	359	462	627	748
A13	Good	2880	50	2.09	165	406	591	786	1044	1258
A14	Good	2880	50	1.8	89	205	285	369	487	582
A15	Good	2880	50	0.97	426	965	1374	1882	2518	3012
A16	Good	2880	41	4.99	43	143	211	289	403	501
A18	Good	540	26	0.01	185	301	390	479	618	714
B01	Good	1440	79	0.04	7	151	312	461	645	779
B02	Good	360	17	6.45	7	23	40	63	100	129
B03	Good	1080	16	0.004	518	806	1029	1259	1631	1891
B04	Good	360	0.26	7.9	24	95	174	263	394	500
C02	Good	720	39	3.7	21	45	61	92	141	184
C03	Good	1800	50	0.834	51	143	199	281	406	475
C04	Good	1080	38	3.4	18	47	63	95	167	219
C06	Good	720	28	2.6	55	89	132	176	242	291

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m³/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
D01	Good	2880	49	4.7	63	199	297	403	579	719
D05	Good	360	0.5	3.8	54	90	125	159	218	268
D06	Good	2880	35	2.4	111	270	385	536	728	877
E01	Good	360	5.5	0.6	11	16	20	25	30	35
E02	Good	720	32	2.3	28	55	89	126	185	230
E03	Good	720	30	3.8	27	59	104	156	237	302
E04	Good	720	12	0.02	56	84	105	128	164	191
E05	Good	720	32	0.7	19	26	36	45	58	68
E06	Good	5760	25	3.3	50	113	176	249	346	425
E07	Good	540	2.05	4.2	53	104	150	201	285	355
E08	Good	360	1.43	7.7	29	71	115	164	259	336
E09	Good	720	19	4.2	59	132	209	302	442	559
E10	Good	1800	46	4.3	72	169	236	357	593	765
E11	Good	2160	50	1.6	10	84	141	232	382	479
E12	Good	720	26	2.04	57	90	124	162	217	261
F02	Good	720	30	2.8	130	240	312	397	510	588
F06	Good	2160	47	2.8	72	221	405	572	789	1007
F07	Good	2160	34	0.17	58	90	117	144	184	210
F09	Good	360	2.85	4.0	84	174	248	324	465	585
F10	Good	2160	39	2.1	68	169	274	363	522	641
F11	Good	720	27	1.78	70	137	198	264	355	424
G02	Good	2880	21	0.8	52	83	116	137	180	212
G03	Good	4320	100	0.3	0	36	60	90	149	176
G04	Good	1440	7	0.2	442	640	786	937	1178	1341
G06	Good	2880	10	6.4	8	27	49	77	117	151

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m³/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
G08	Good	1080	33	0.02	87	135	170	218	279	315
G09	Good	540	5.03	3.3	64	133	199	261	365	445
G10	Good	720	24	1.9	103	217	319	430	613	756
G11	Good	720	12	0.1	200	273	332	393	504	588
G12	Good	720	23	1.1	87	129	171	210	278	327
G14	Good	2160	2.41	1.7	115	238	348	468	636	774
G16	Good	2880	22	0.0004	376	565	718	866	1175	1326
G18	Good	2880	80	0.6	9	109	199	321	495	620
G19	Good	2880	73	4	5	54	118	196	318	428
H01	Good	360	25	2.12	6	12	16	21	28	33
H02	Good	1800	31.7	1.43	165	327	451	586	800	961
H03	Good	1440	42	2.3	62	175	285	406	601	753
H04	Good	1440	38	0.03	381	564	713	857	1047	1196
H05	Good	720	13	1.8	208	340	428	524	679	793
H06	Good	1440	33	1.7	118	202	271	352	476	566
H07	Good	1080	3.8	0.0004	408	575	694	817	995	1139
H08	Good	1080	7.7	0.001	589	800	965	1131	1363	1547
H09	Good	1080	46	4.0	25	81	145	213	319	405
H11	Good	360	3.3	0.0009	22	30	37	44	52	59
H12	Good	720	32	0.2	224	355	444	544	679	784
H13	Good	360	18	0.05	39	62	81	99	125	147
H14	Good	1440	46	1.0	191	361	508	650	849	1006
H15	Good	4320	49	0.6	148	350	488	619	808	969
H16	Good	2160	50	0.8	438	777	1054	1297	1693	2024
H17	Good	720	35	2.1	65	113	157	203	275	327

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
H18	Good	360	12	5.0	50	99	142	185	252	309
H19	Good	360	8.9	0.1	42	57	70	80	99	111
H20	Good	1440	50	2.0	79	205	316	424	584	710
H21	Good	2160	25	0.1	224	311	394	477	600	692
H22	Good	2160	48	2.09	100	248	390	497	711	887
H25	Good	360	18	5	88	209	317	421	583	718
H26	Good	720	64	4.8	29	79	132	202	307	393
H28	Good	720	50	3.9	68	178	308	453	645	801
H30	Good	1440	14	1.7	658	1148	1504	1867	2394	2823
H31	Good	360	20	1.7	184	283	365	436	557	647
H32	Good	1440	45	0.7	662	1102	1401	1696	2079	2376
H33	Good	1440	50	3.2	299	664	928	1192	1559	1845
I01	Good	360	5.6	4.2	33	61	87	113	155	190
I04	Good	2160	40	1.7	240	526	785	1064	1458	1769
I05	Good	180	0.09	8.8	22	50	74	98	132	162
I07	Good	360	45	4.9	24	65	97	139	198	240
I08	Good	1440	50	0.07	46	230	370	512	759	942
I09	Good	360	7.03	7.3	42	99	149	200	298	369
I10	Good	1440	50	0.3	64	194	298	409	602	742
I12	Good	720	50	3.3	29	68	102	139	195	237
I13	Good	1800	32	1.6	140	290	415	558	818	1015
I14	Good	720	29	0.004	105	231	327	430	618	765
I15	Good	720	27	2.7	58	118	177	243	352	432
I16	Good	720	18	0.5	187	298	385	472	609	721
I19	Good	720	18	4.1	376	746	1024	1355	1795	2111

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
I20	Good	1800	45	5	215	570	896	1236	1711	2070
I21	Good	1800	19	1.62	216	337	430	547	724	849
I22	Good	360	50	5	199	427	588	777	1062	1275
I23	Good	1800	50	1.4	186	323	437	539	707	831
I28	Good	360	20	1.4	120	190	253	306	402	468
I29	Good	360	25	0.0004	362	567	712	902	1175	1371
I30	Good	720	27	1.7	498	845	1088	1402	1841	2165
J01	Good	2880	45	2.07	57	117	188	239	342	414
J02	Good	1440	30	2.2	123	248	372	501	719	902
J03	Good	360	26	4.8	5	11	18	23	33	42
J04	Good	1440	49	0.02	81	203	283	360	500	599
J05	Good	5760	35	0.002	110	170	218	270	347	412
J06	Good	2880	50	0.7	108	273	382	487	651	778
J07	Good	2880	50	1.1	174	305	404	558	921	1100
J08	Good	2160	50	2.7	9	52	102	170	286	396
J09	Good	2880	36	1.1	86	143	208	260	356	421
J10	Good	1440	38	2.1	77	179	289	413	594	745
J11	Good	1440	36	2.4	78	171	264	372	556	714
J12	Good	1440	45	0.003	76	206	294	388	548	688
J13	Good	2880	24	1.5	189	331	476	606	892	1103
J14	Good	1440	17	0.4	373	581	751	931	1222	1454
J15	Good	2880	24	0.7	373	585	770	966	1335	1578
J17	Good	1440	33	2.6	97	217	347	485	723	933
J18	Good	720	0.02	1.9	282	464	603	744	967	1153
J19	Good	2880	13	0.0004	219	312	388	457	576	653

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
J20	Good	1440	50	0.4	63	150	204	271	403	494
Cox Kelpie	Good	1440	14	1.7	486	927	1287	1669	2200	2600
Jooriland	Good	2880	40	0.9	792	1712	2476	3284	4331	5154
Nattai Causeway	Good	2160	16	1.3	188	357	492	622	799	927
Nepean	Good	1080	30	4.8	354	984	1526	2106	2864	3446

Table C4 Metadata and design flood estimates associated with the FFA-Reconciled Losses method for catchments investigated in this study with potential issues in their At-Site FFA fits

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
A02	Bad	1080	24	2.7	262	546	784	996	1382	1687
A04	Bad	1080	28	0.1	109	180	230	284	364	418
A17	Bad	540	6.6	0.002	29	42	51	62	79	90
C05	Bad	360	1.5	18.1	1	4	7	11	17	22
D02	Not Modelled	270	42.5	26	0	1	3	5	8	11
D03	Rainfall	540	40	2.5	114	231	311	394	529	615
D04	Rainfall	1080	1.6	0.002	1049	1547	1931	2291	2947	3397
D07	Bad	1080	19	0.005	193	295	368	437	544	613
D08	Bad	540	4.8	0.001	332	462	559	660	825	932
F01	Rainfall	540	26	0.008	123	198	254	313	406	475
F03	Urban	360	5.2	0.004	187	261	317	384	482	555
F04	Urban	2160	42	1.04	67	122	168	219	286	334
F05	Bad	540	0.6	0.003	88	120	142	165	200	227
F08	Bad	360	7.4	0.031	51	70	85	99	123	138
G01	Bad Calibration	360	0.5	7.6	22	57	91	125	176	218
G05	Bad Calibration	360	0.3	9.7	4	10	16	20	25	30
G07	Bad FFA	360	5.9	11	18	63	114	149	208	266
G13	Bad Calibration	720	1.1	4.1	53	128	207	303	457	589
G15	Bad	1080	12	0.5	202	298	335	437	579	679

Station	Fit Quality	Critical Duration 10% AEP (hr)	IL (mm)	CL (mm/hr)	Peak Flow (m^3/s)					
					50% AEP	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
G17	Bad	1800	2.7	0	405	553	653	776	959	1078
H10	Bad	360	3.6	0.005	109	155	191	221	268	307
H23	Bad	360	22	8.0	12	33	54	81	123	158
H24	Bad	720	0.5	0.0016	263	370	445	532	668	770
H27	FFA	270	1.5	14	13	37	67	112	182	244
H29	FFA	180	3.9	12	22	64	104	142	198	248
I02	Bad	720	0.5	0.0003	473	679	822	976	1211	1394
I03	FFA	360	2.5	8.6	39	96	154	233	1458	477
I06	Bad	720	31	0.01	149	242	306	381	491	568
I11	FFA	720	35	1.6	526	1086	1535	1988	2581	3049
I17	FFA	360	20	5	93	171	237	308	425	508
I18	Rainfall	360	50	3.3	28	61	90	114	147	177
I24	Rainfall	360	17	10	120	289	441	611	888	1096
I25	Rainfall	360	12	0	126	189	242	282	356	409
I26	Rainfall	720	19	0	319	515	645	784	967	1120
I27	Rainfall	720	16	0.0016	210	318	394	490	622	719
J16	Bad	1440	1.6	0.00014	465	631	746	864	1052	1191
J21	Bad	1080	3.3	0.008	508	684	800	962	1206	1367