APPENDIX S

THE DNR'S SEDIMENT TRANSPORT TECHNICAL DOCUMENTATION

1 Introduction

As part of their modeling work, Enbridge provided DNR with sediment transport model outputs from SSFATE, a sediment transport model typically used for dredging operations by the US Army Corps of Engineers (Johnson et al., 2000; Swanson et al., 2007).

To visualize the impact of modeled sediment transport scenarios on real streams, DNR mapped sediment transport predictions from the model to waterways with roughly analogous matches in terms of dimensions to visualize the potential for sediment impacts. DNR also applied sediment transport to show the potential for additive effects due to crossings that are either near confluences or in close proximity to one another on the same watercourse.

1.1 Problem Statement

Mapping sediment transport outputs to streams requires assigning, for each distance step along a certain watercourse shape, a sediment concentration value from model predictions. This requires several steps:

1. Fitting a continuous function to the binned outputs of the model to estimate the values of intermediate distances.
2. Creating a machine-traversable representation of the stream network on which to assign values from fitted interpolations.
3. Mapping sediment outputs correctly to the network representation using a traversal algorithm.
4. Correctly handling intersection topology for the machine representation of the stream network.
5. Visually representing the information in GIS software.

2 Technical Implementation

To map predicted values to stream polygons, DNR created a graph representation of the project area's stream network in python and created a traversal algorithm to assign values to points in the network's geometry based on network position. This process involved steps in QGIS, ArcGIS Pro, and python, with extensive use of the `shapely`, `scipy`, `networkx`, and `geopandas` libraries.

2.1 Data Sources

The stream network used for analysis was digitized with additional detail specifically to cover identified stream crossings in the project domain, extending DNR's existing 1:24k hydro data layer.

Outputs for sediment transport were sourced from RPS's SSFATE modeling runs, reported on in appendix AB.

2.2 Interpolation of model outputs

Interpolation of model outputs was performed using `scipy.optimize`, a package which allows for non-linear least-squares curve fitting. The general form of the concentration function is exponential decay, which allow for fairly close fitting of their curve (with some residual error) using an optimization function as an interpolator. Each of the 36 scenarios was fit individually using the `curve_fit` function and initial guesses of correct parameters.

```python
for scen in scenlist:
    try:
        res = curve_fit(
            lambda distance, b, c: (scen["concentration"][0] - c)
            * np.exp(-b * distance)
            + c,
            scen["distance"],
            scen["concentration"],
            p0=(0.1, 0),
            full_output=True,
            bounds=([0, 0], [np.inf, np.inf]),
        )
        results.append(res)
        conditions.append(np.linalg.cond(res[1]))
        residuals.append(res[2]["fvec"])
        stderrs.append(np.sqrt(np.diag(res[1])))
    except:
        results.append(0)
        continue
```

Listing 1: Fitting snippet showing `scipy.optimize` code used to process each individual case for regression parameters.

Each regression was then plotted and evaluated against its individual scenario run. Complete plots are in Section 4.1.

2.3 Creating Machine-Traversable Stream Network

The stream network polygons in the project area were made machine-traversable using a graph representation. In particular, stream networks are generally Directed Acyclic Graphs (DAGs); a DAG is a graph which has directional linkages and which does not loop back on itself, only forming a branching structure. Graphs are well-supported computer data structures with rich library support. The python library `networkX` and some additional functionality from the package `momepy` were used to construct a directed acyclic graph representation of the stream network in the project area. Graph nodes represented confluences in the stream network, and edges contained the geometry of each flowline. Figure 1 demonstrates the translation of the stream network to a DAG, facilitated by the python package `momepy` which build on top of the functionality in `networkX`.

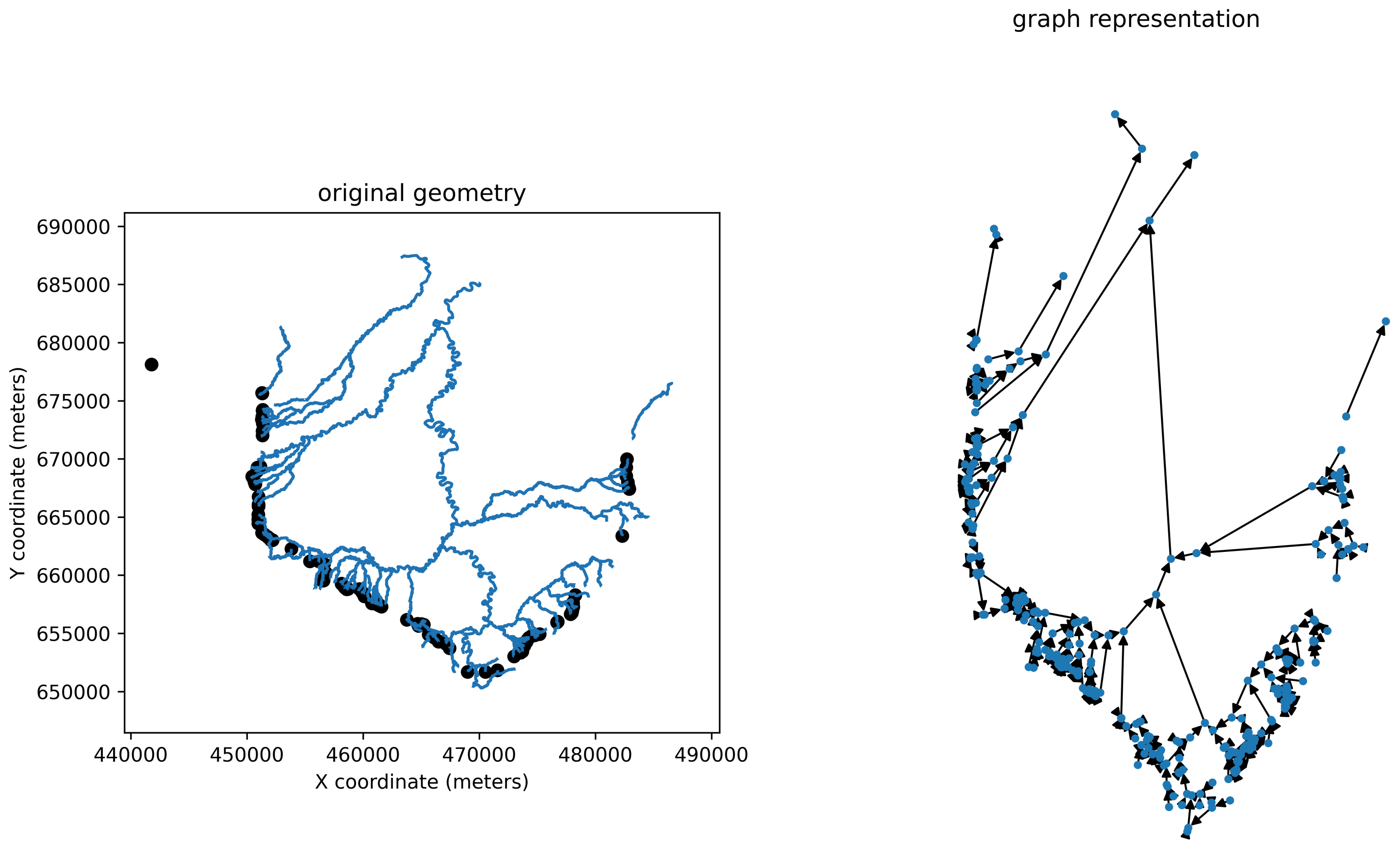

Figure 1: Original geometry and graph representation of stream network in the project area's connected network.

2.4 Mapping Sediment Outputs Onto Streams

Because each linestring is stored in an edge, and because `networkX` allows efficient traversal of nodes and edges in networks in a distance-aware manner, it is easy to return an array of geometries which constitute a particular flow path through the network. The flowlines (stored as `shapely` linestrings) were joined using shapely primitive operations to produce one complete flowline for every sediment transport path.

Linestrings are formed independently and have overlaps similar to Figure 2. For example, linestrings A and B both overlap between nodes C and E; therefore edge CE is the sum of the sediment outputs from A and B. Sections in this higher-order graph representation are defined by overlaps or singleton sediment outputs, which are a subset of all linestrings. `shapely` operations are used in the program to perform spatial sums on equivalent linestrings (for example, edge EF has the same representation in A, B, and D, so these are identical linestrings).

After each of the subsections with overlaps are computed, a final set of polygons which mirrors the original stream graph representation is back-converted such that each linestring contains the measure values of the constituent polygons.

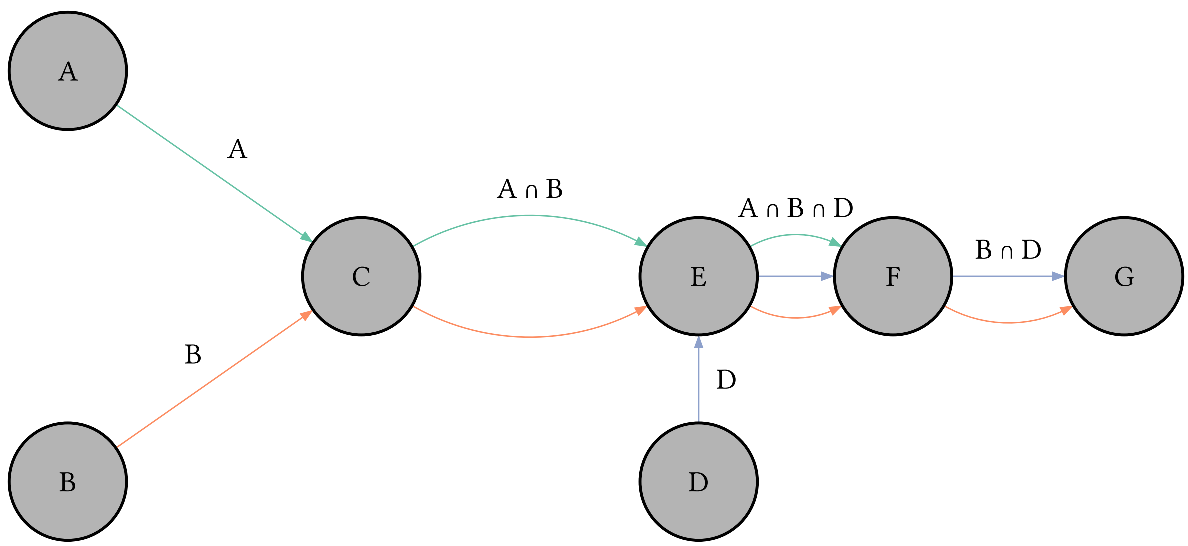

Figure 2: Conceptual diagram illustrating the path tracing for the graph representation of the stream network.

2.5 Visual Representation in GIS Software

Measure values in the stream network are legible to QGIS, which can represent them as variable buffer widths on a per line segment basis. This allows representation of the sediment plume with some qualitative abstractions to visualize different aspects of the dataset.

3 Limitations

This approach inherits limitations of the original SSFATE modeling outputs. These limitations include the inaccuracy of the flow geometry and magnitude estimation, as well as the sediment compositions assumed by the model. This sediment representation also introduces inaccuracy in the curve fit for each sediment scenario. This output does not calculate dilution. Typically, confluence points are outside the area of highest sediment concentration, meaning that the relative error of this approach is limited even when dilution is not considered. The other scenario (additive inputs on the same stream) does not add flow with additional suspended sediment, so this case is modeled accurately by the tool.

4 Outputs

4.1 Individual Regression Plots

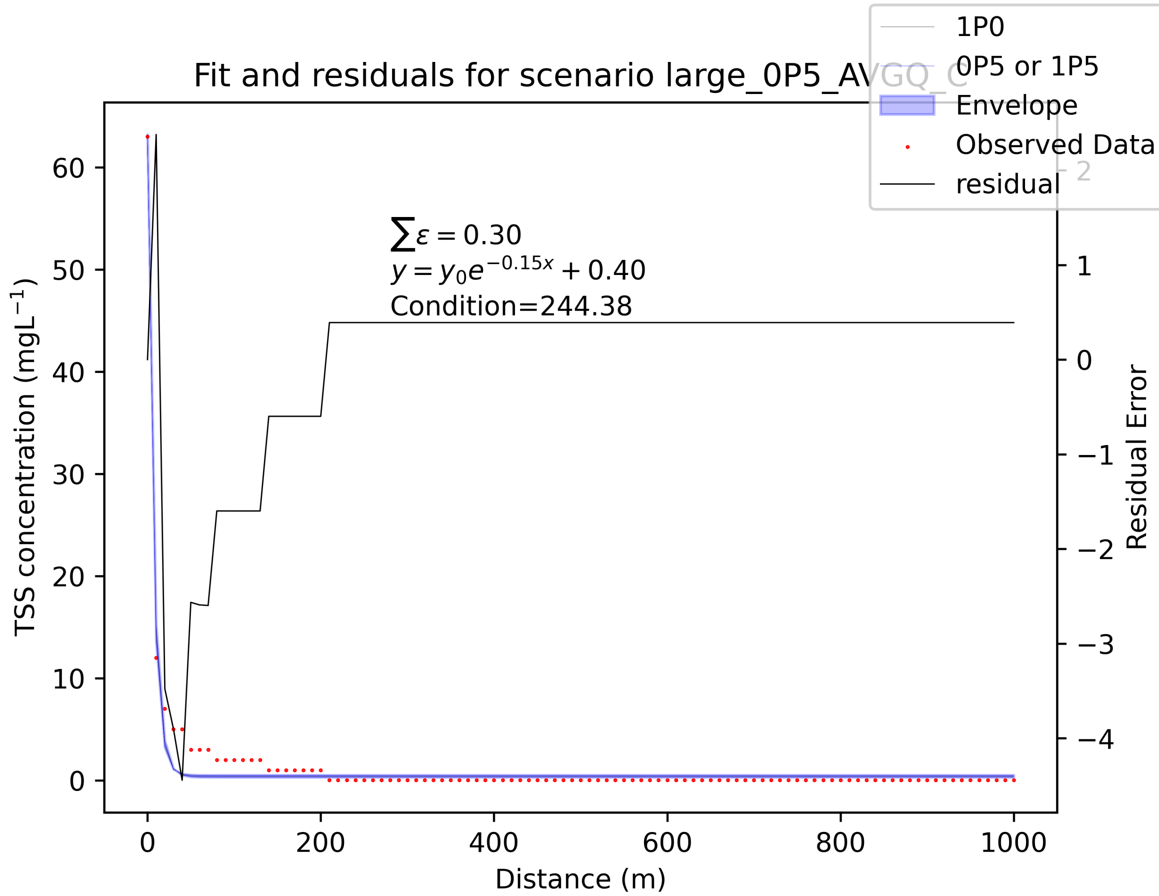

Figure 3: Fit and residual for the scenario with large stream size, 50% loading, and coarse sediment with average flow.

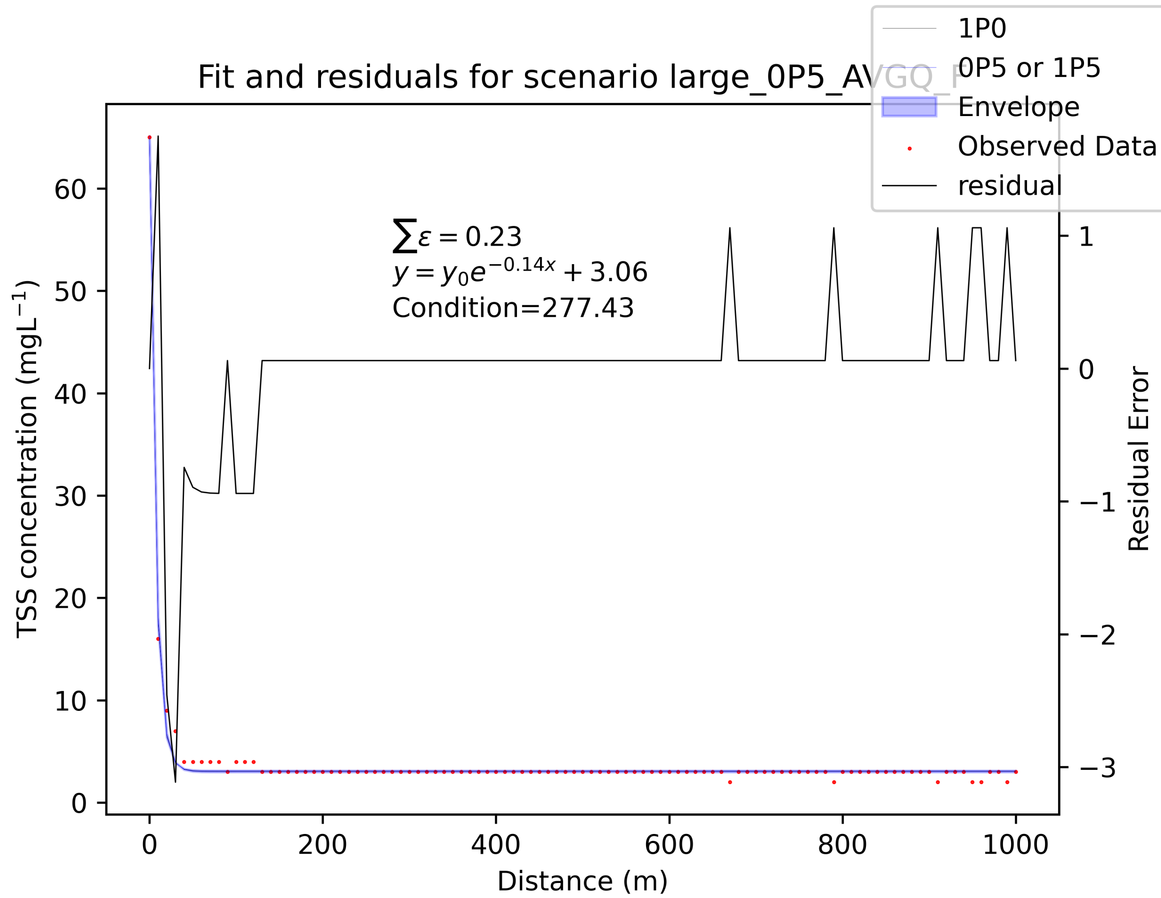

Figure 4: Fit and residual for the scenario with large stream size, 50% loading, and fine sediment with average flow.

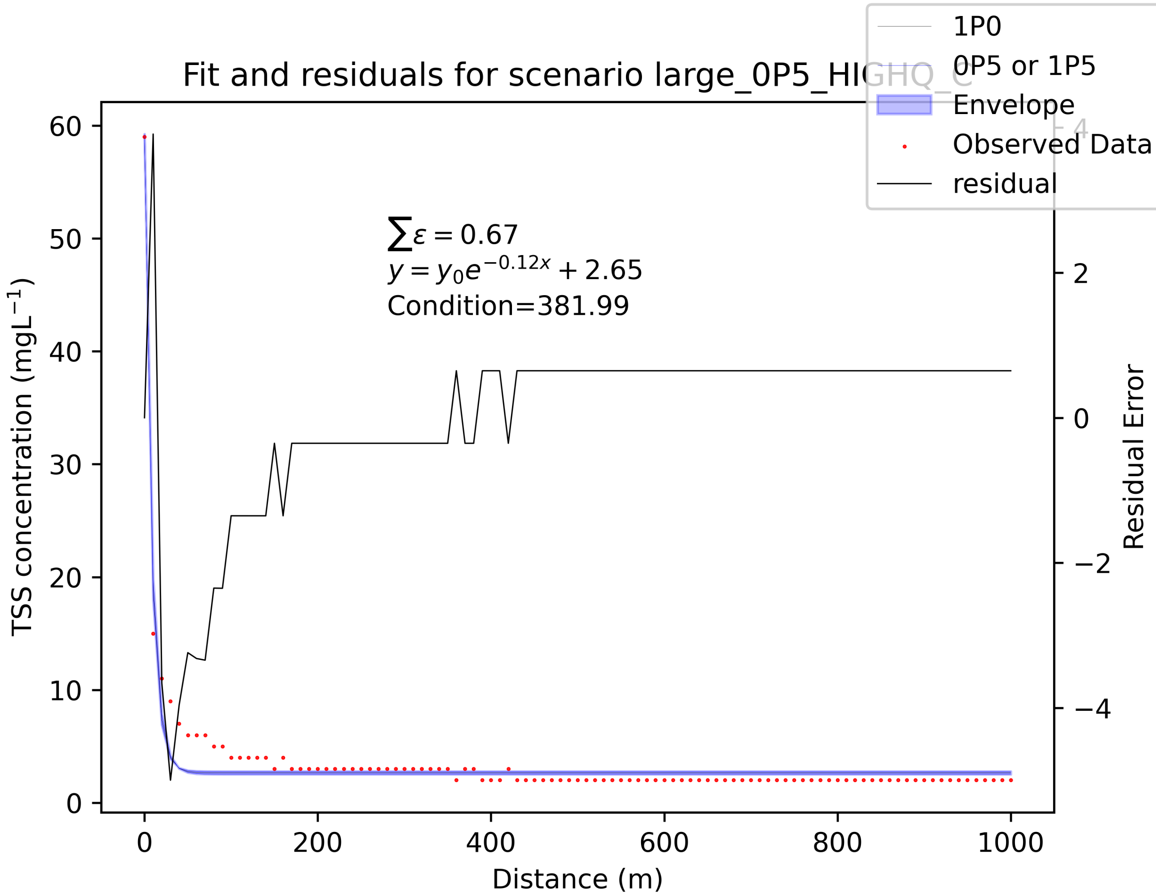

Figure 5: Fit and residual for the scenario with large stream size, 50% loading, and coarse sediment with high flow.

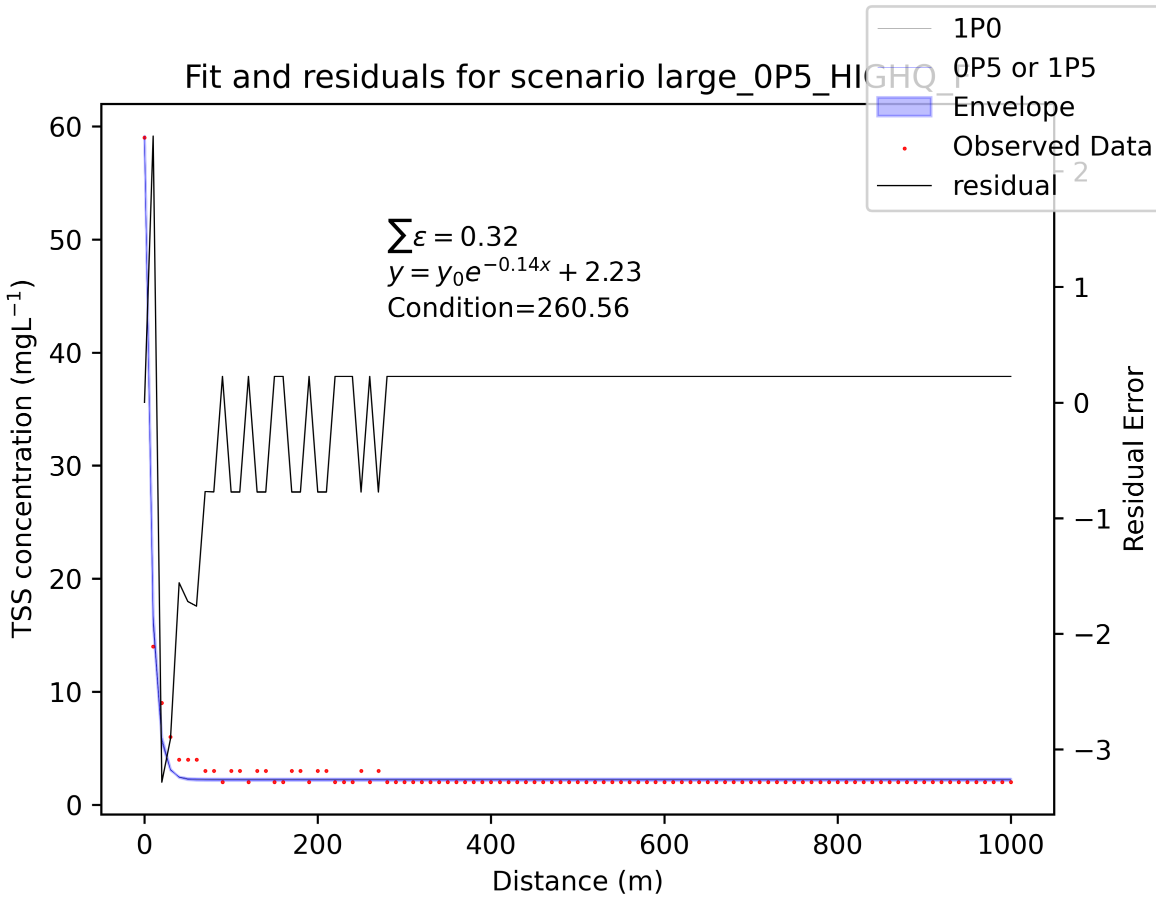

Figure 6: Fit and residual for the scenario with large stream size, 50% loading, and fine sediment with high flow.

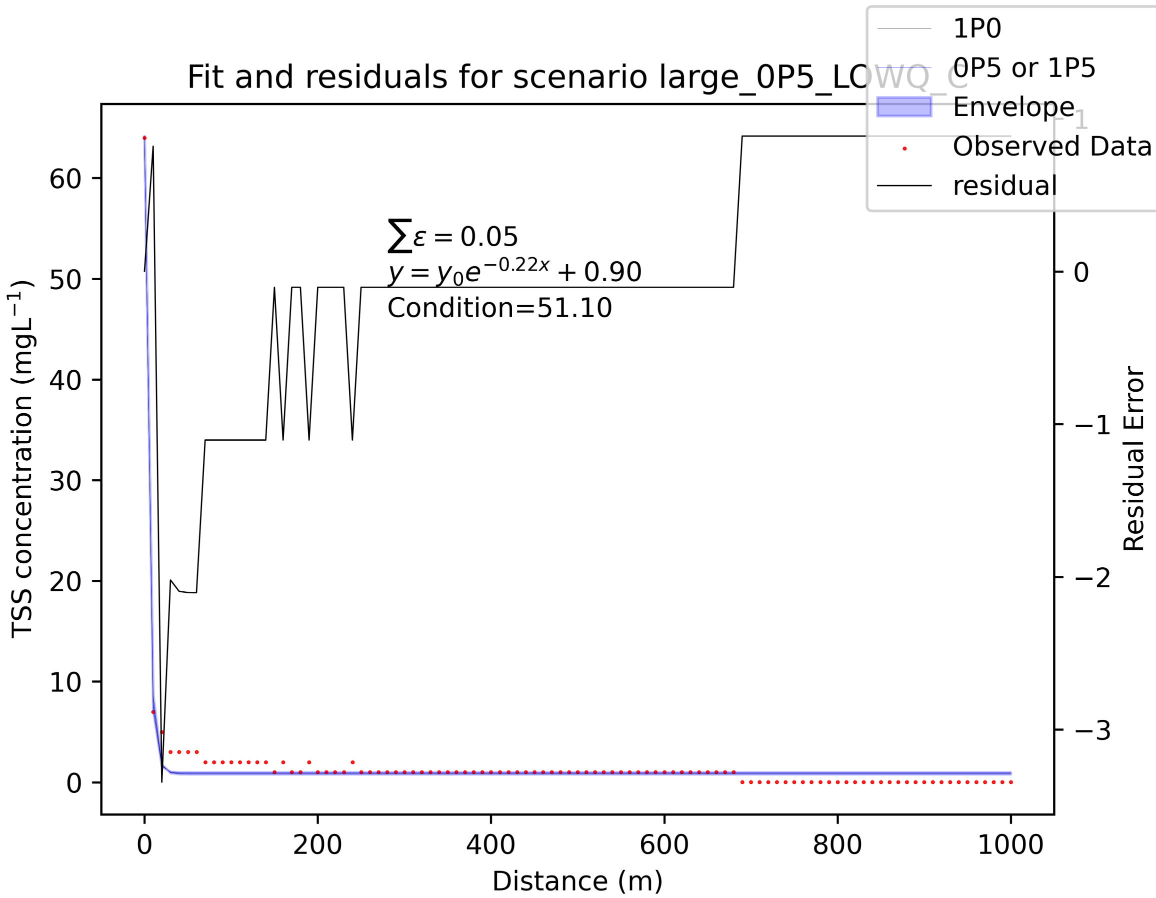

Figure 7: Fit and residual for the scenario with large stream size, 50% loading, and coarse sediment with low flow.

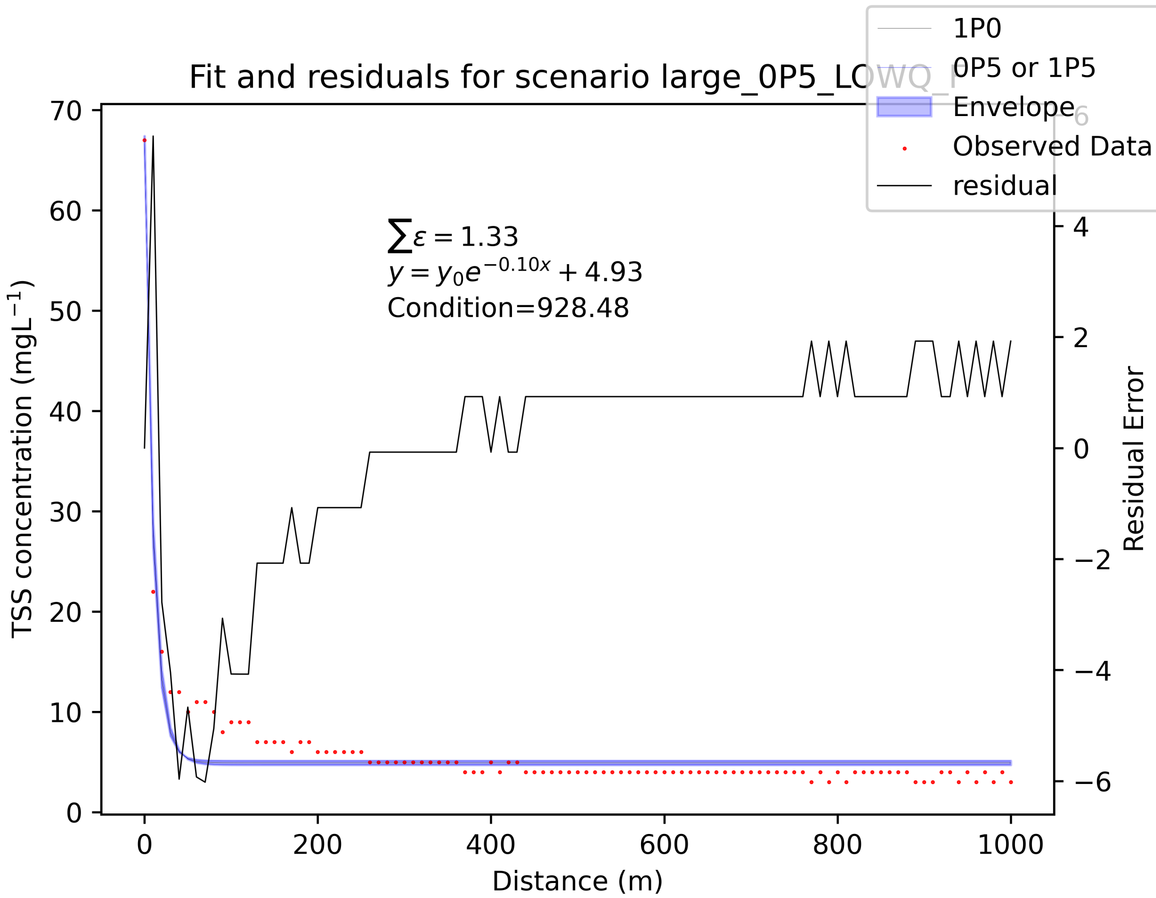

Figure 8: Fit and residual for the scenario with large stream size, 50% loading, and fine sediment with low flow.

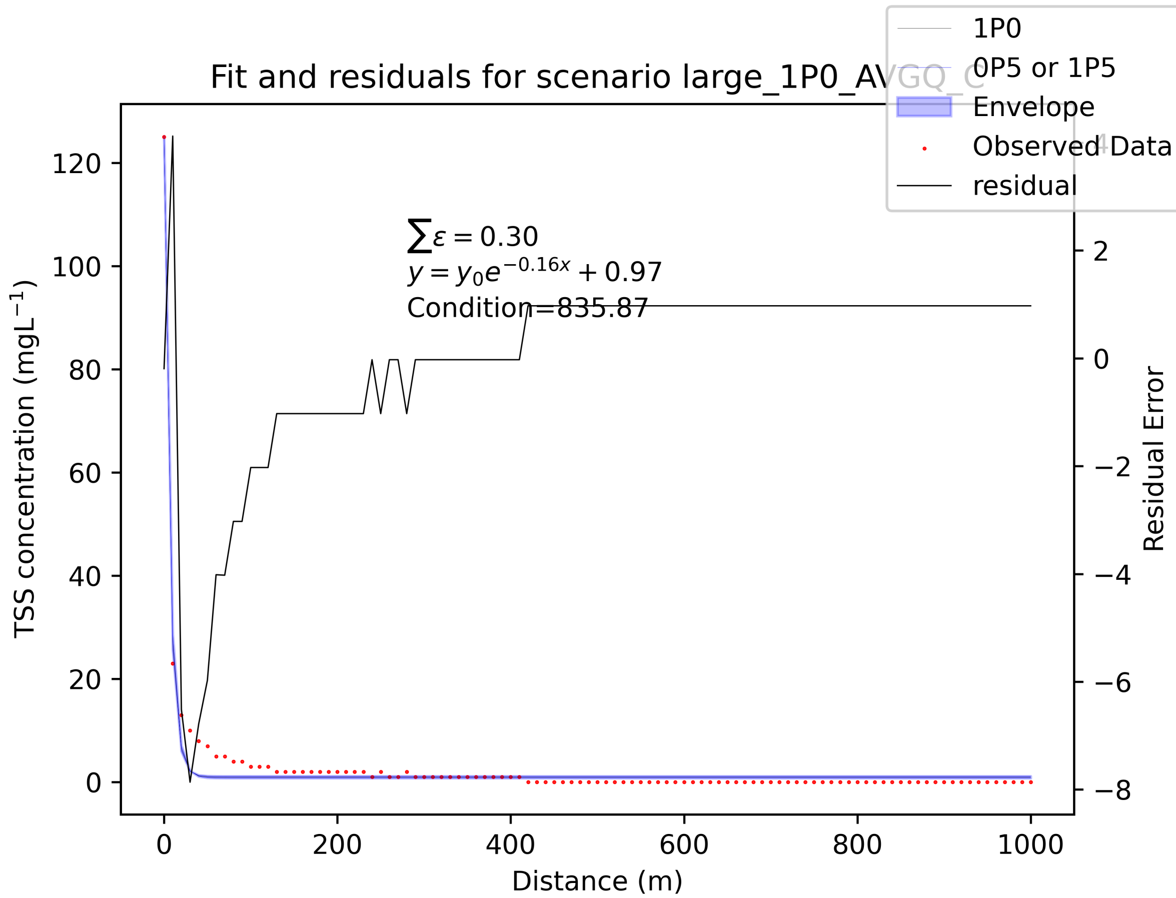

Figure 9: Fit and residual for the scenario with large stream size, 100% loading, and coarse sediment with average flow.

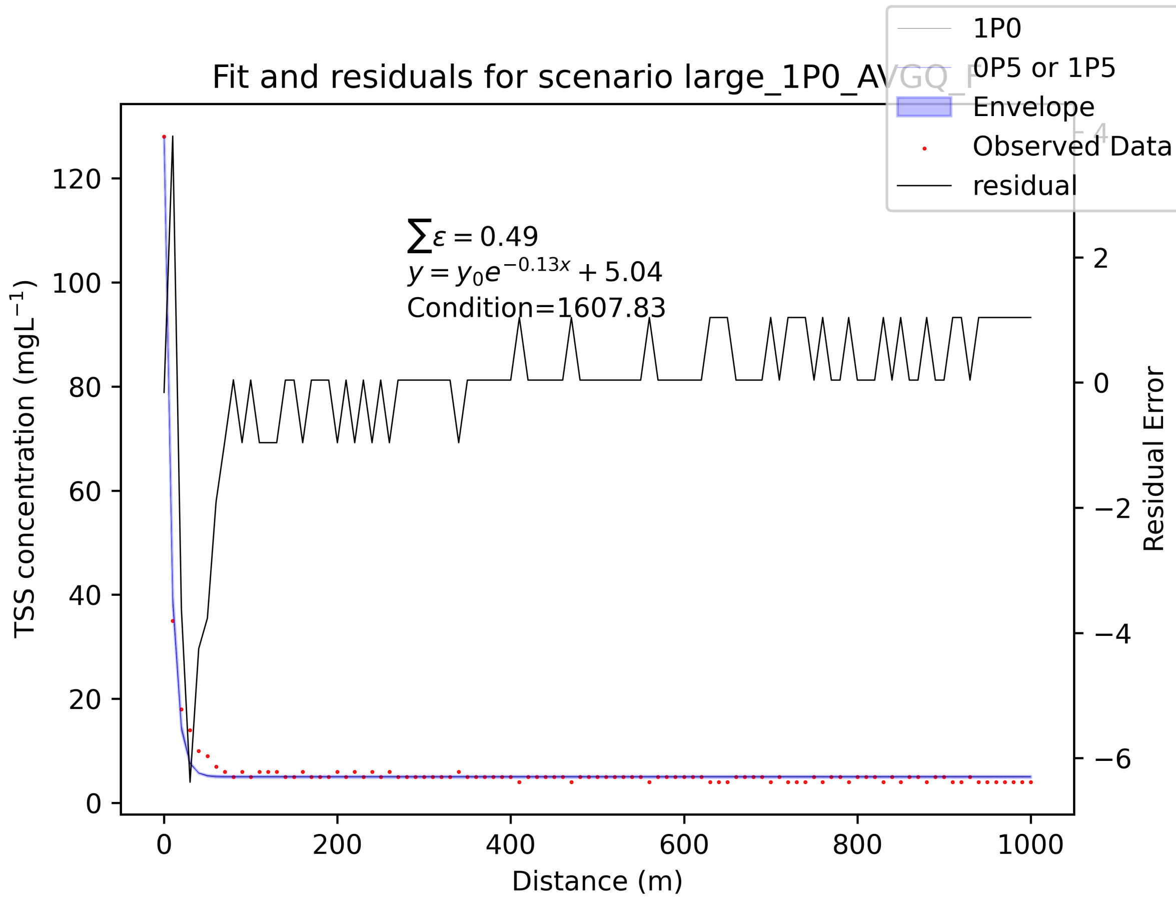

Figure 10: Fit and residual for the scenario with large stream size, 100% loading, and fine sediment with average flow.

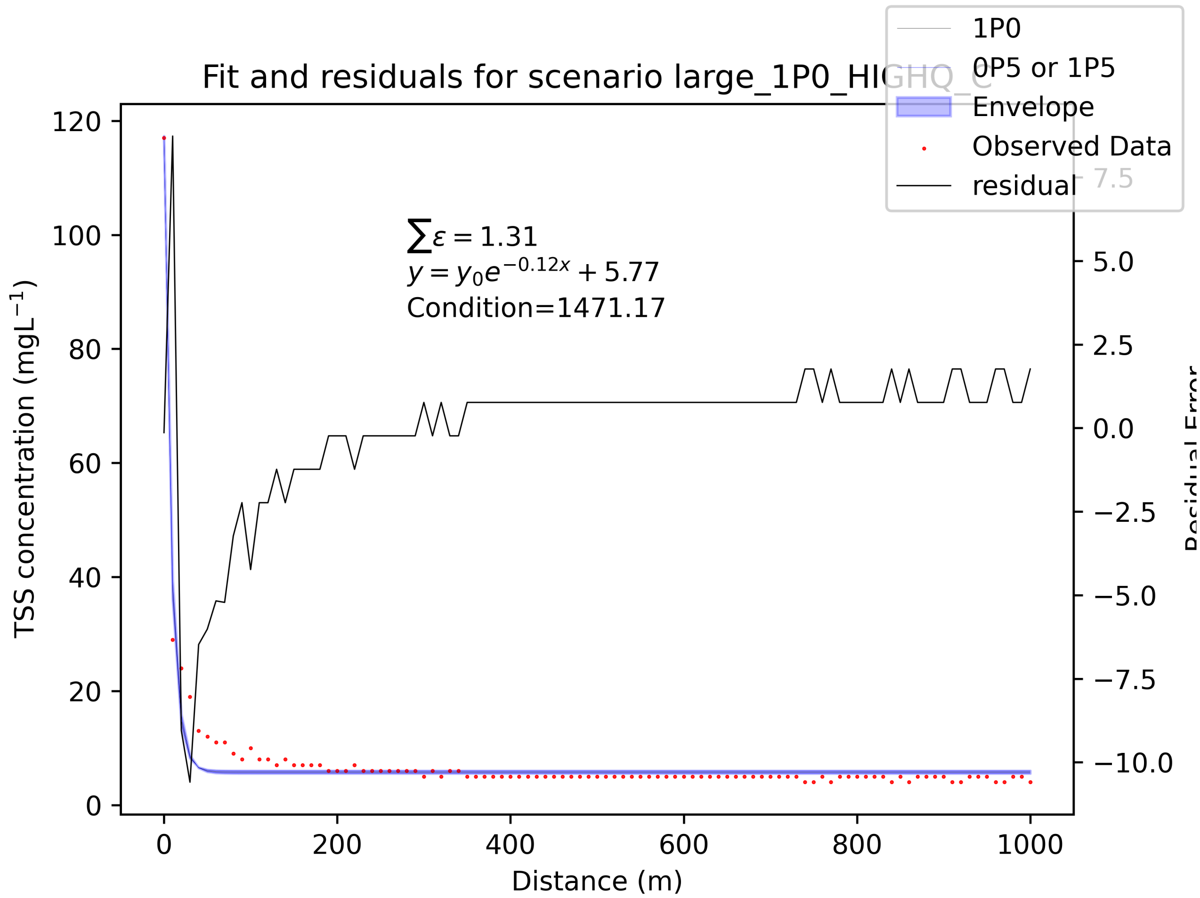

Figure 11: Fit and residual for the scenario with large stream size, 100% loading, and coarse sediment with high flow.

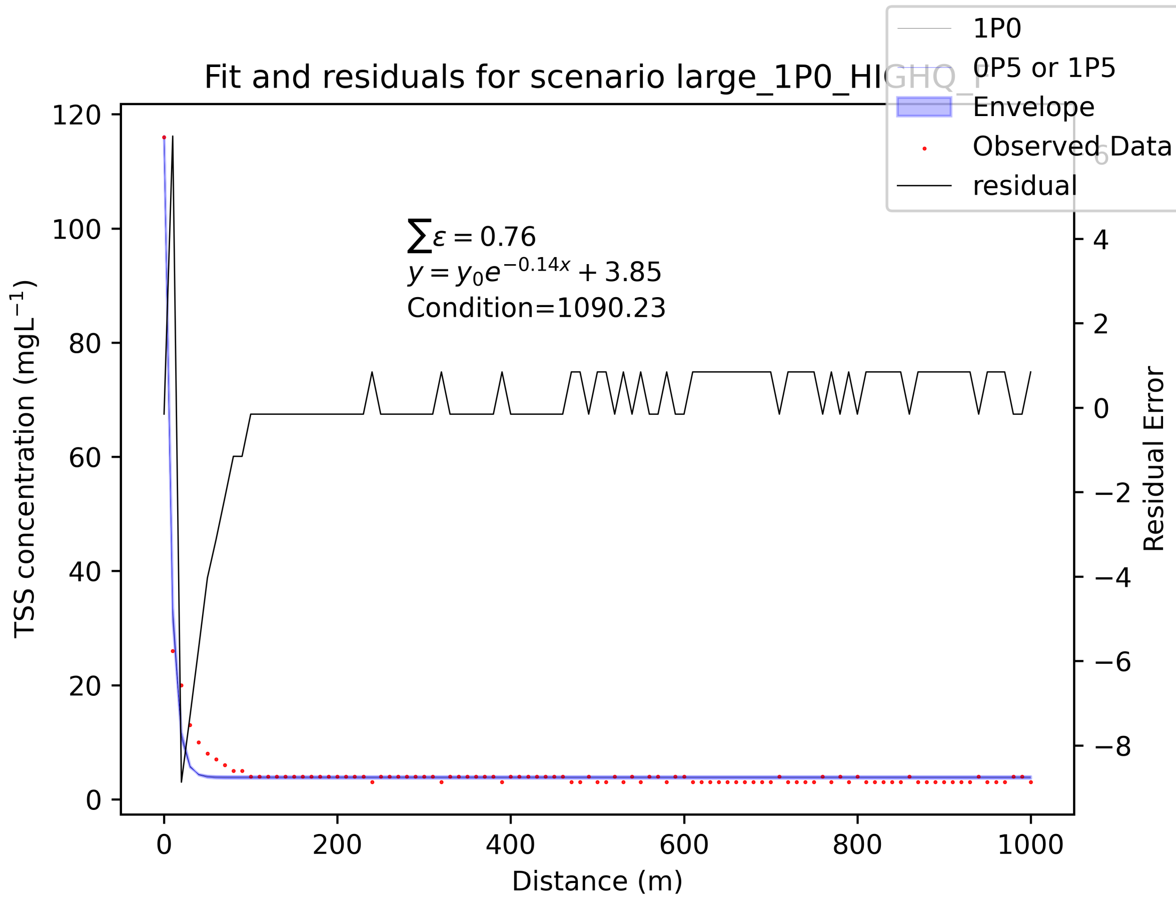

Figure 12: Fit and residual for the scenario with large stream size, 100% loading, and fine sediment with high flow.

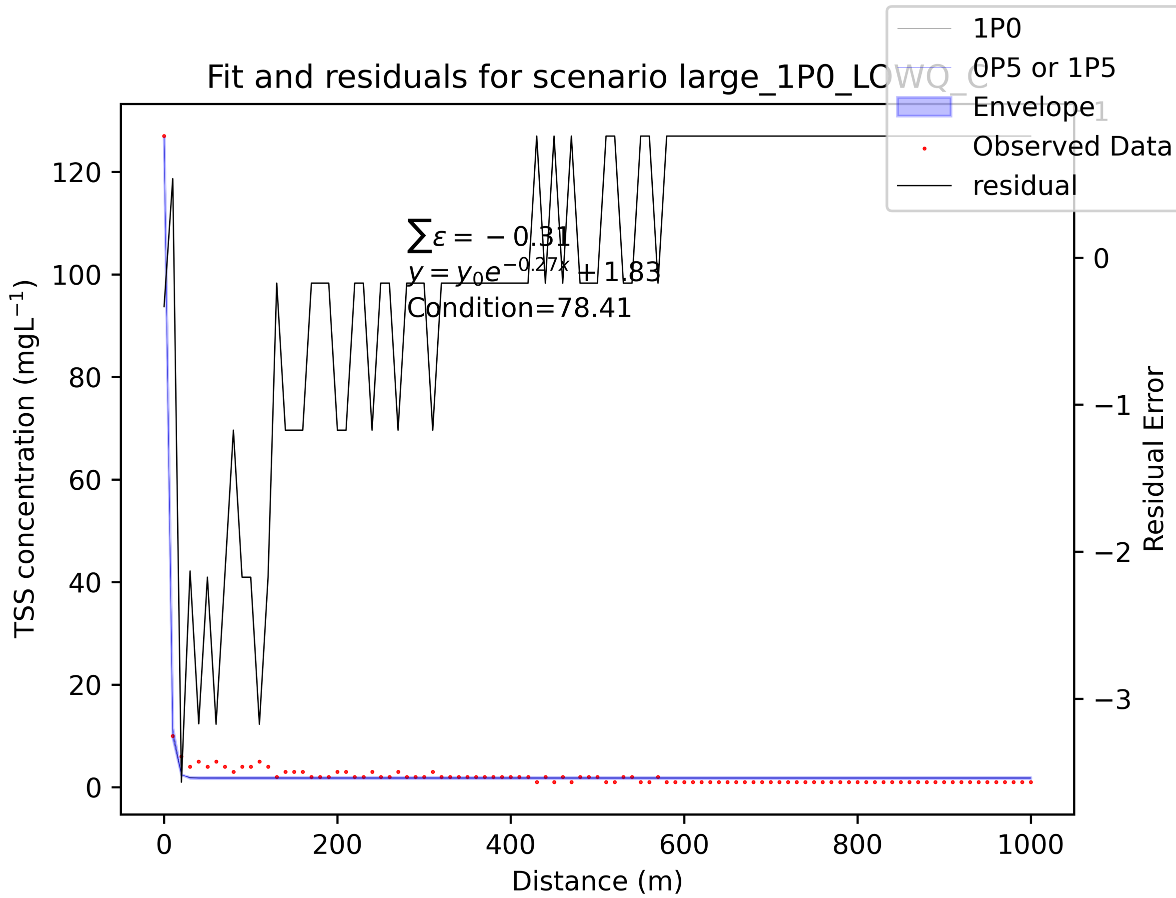

Figure 13: Fit and residual for the scenario with large stream size, 100% loading, and coarse sediment with low flow.

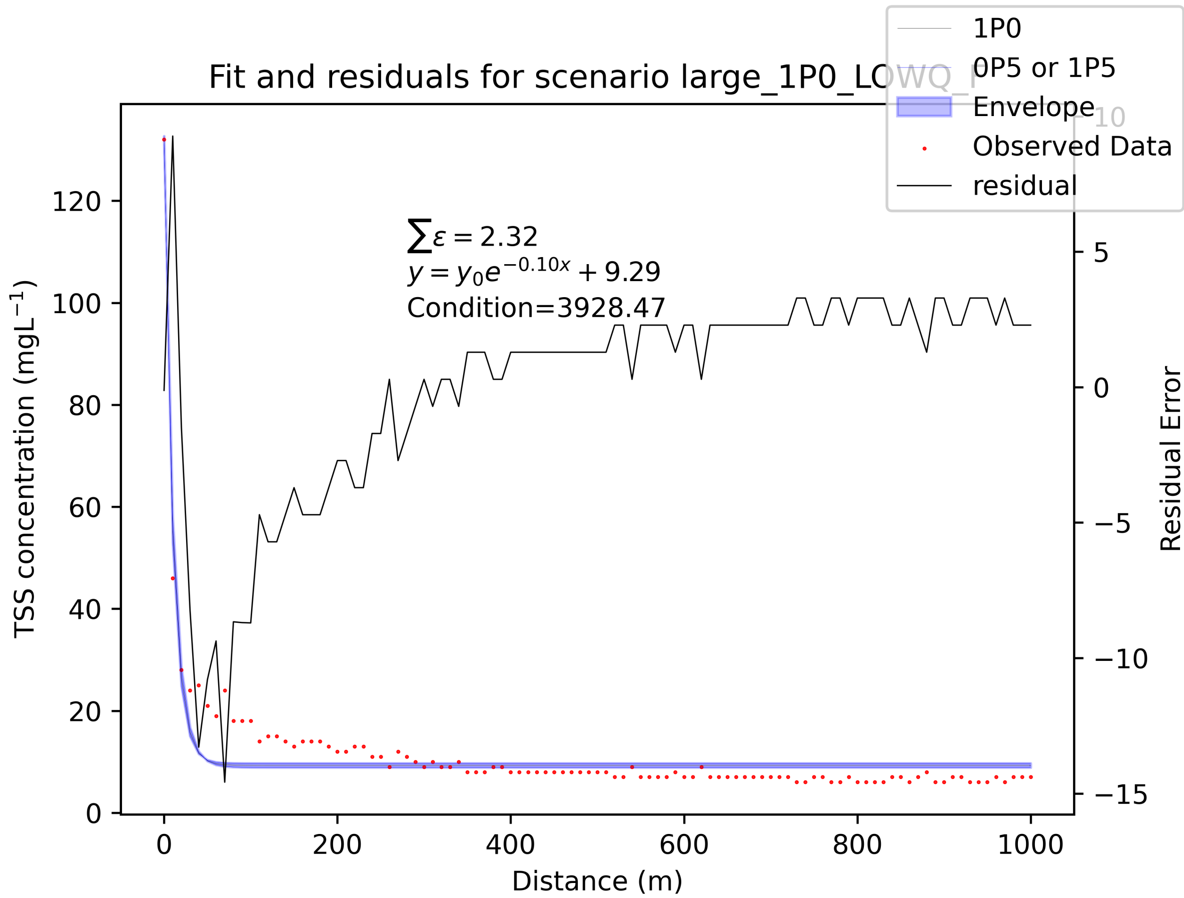

Figure 14: Fit and residual for the scenario with large stream size, 100% loading, and fine sediment with low flow.

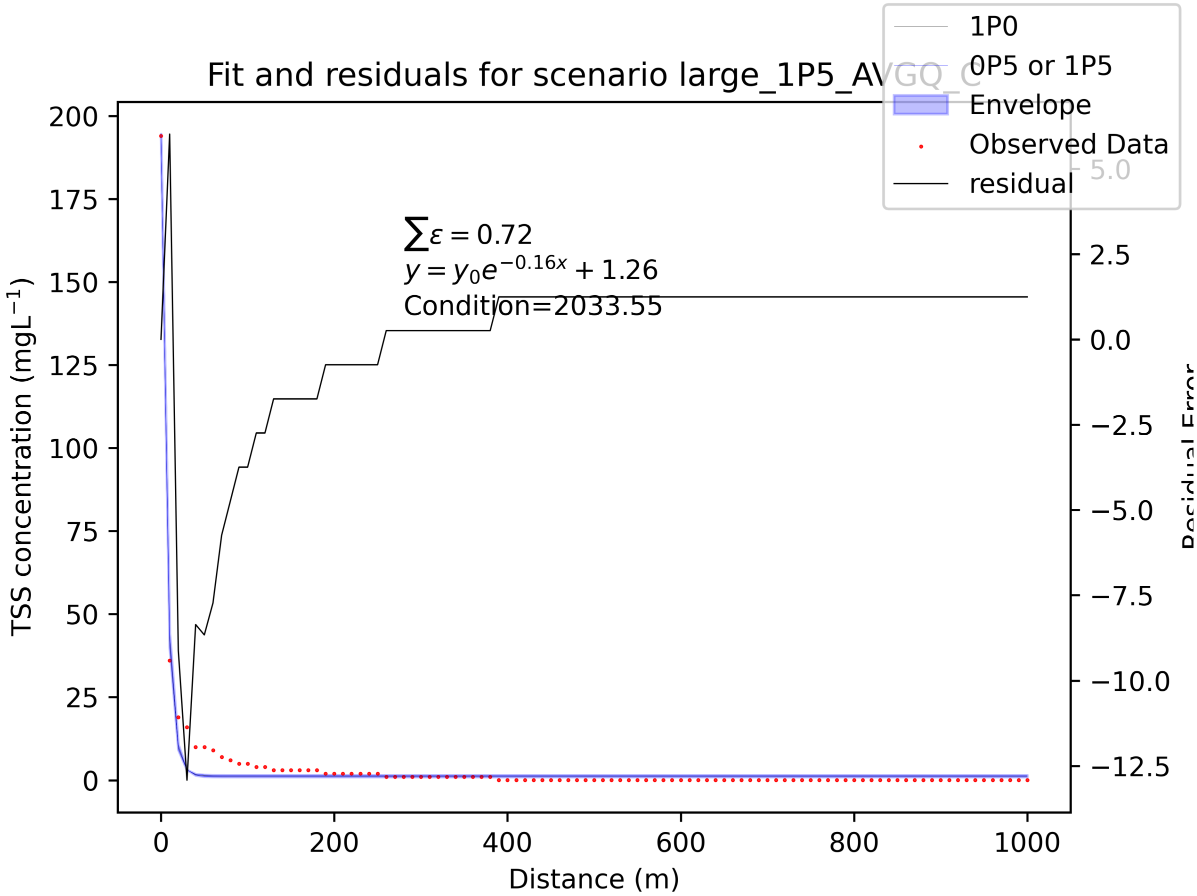

Figure 15: Fit and residual for the scenario with large stream size, 150% loading, and coarse sediment with average flow.

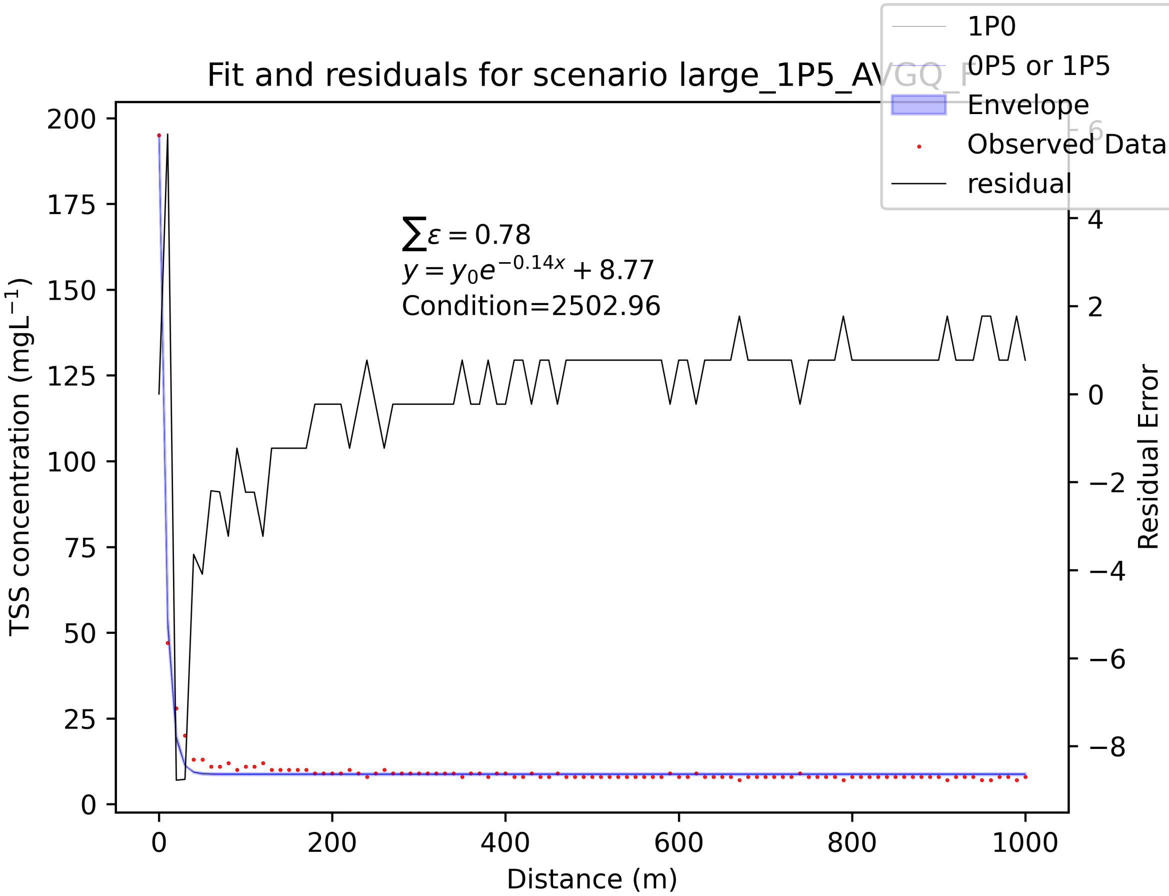

Figure 16: Fit and residual for the scenario with large stream size, 150% loading, and fine sediment with average flow.

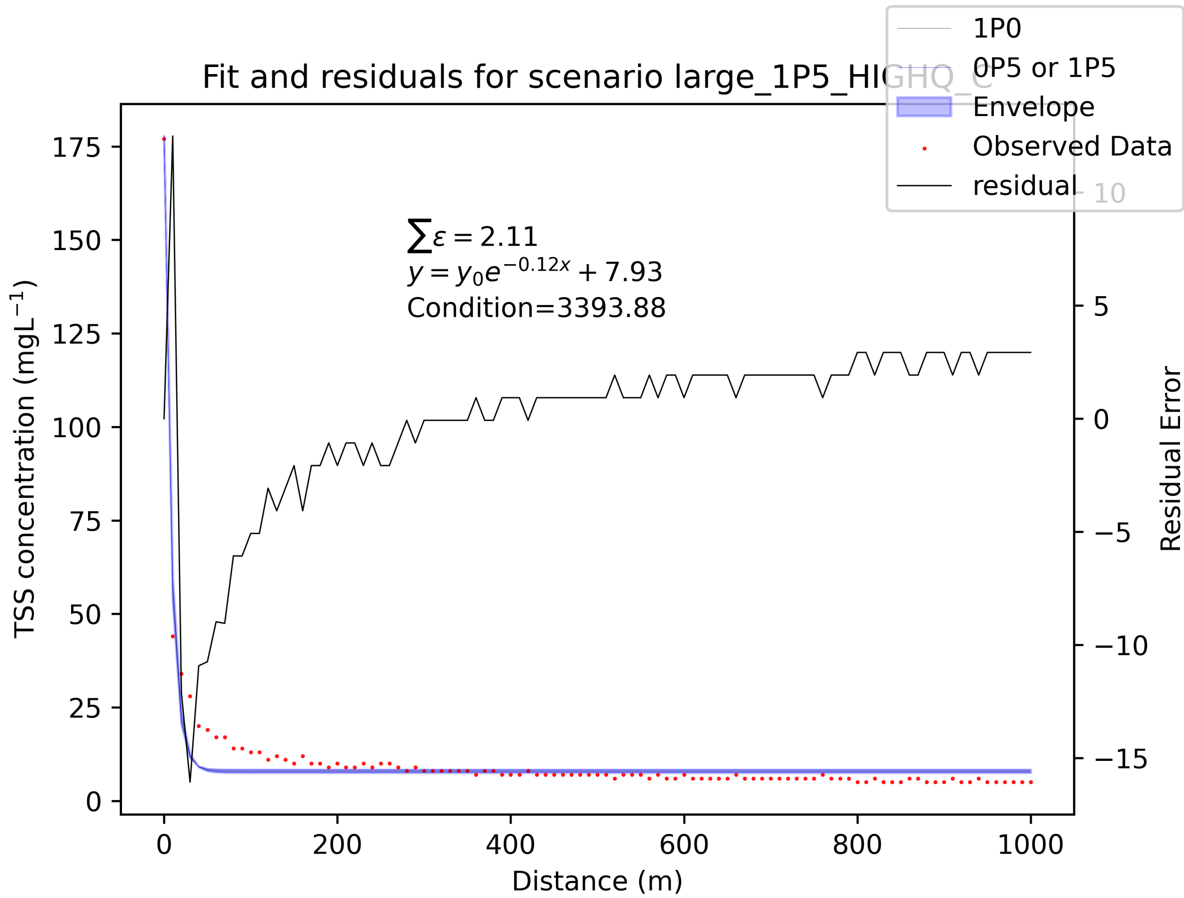

Figure 17: Fit and residual for the scenario with large stream size, 150% loading, and coarse sediment with high flow.

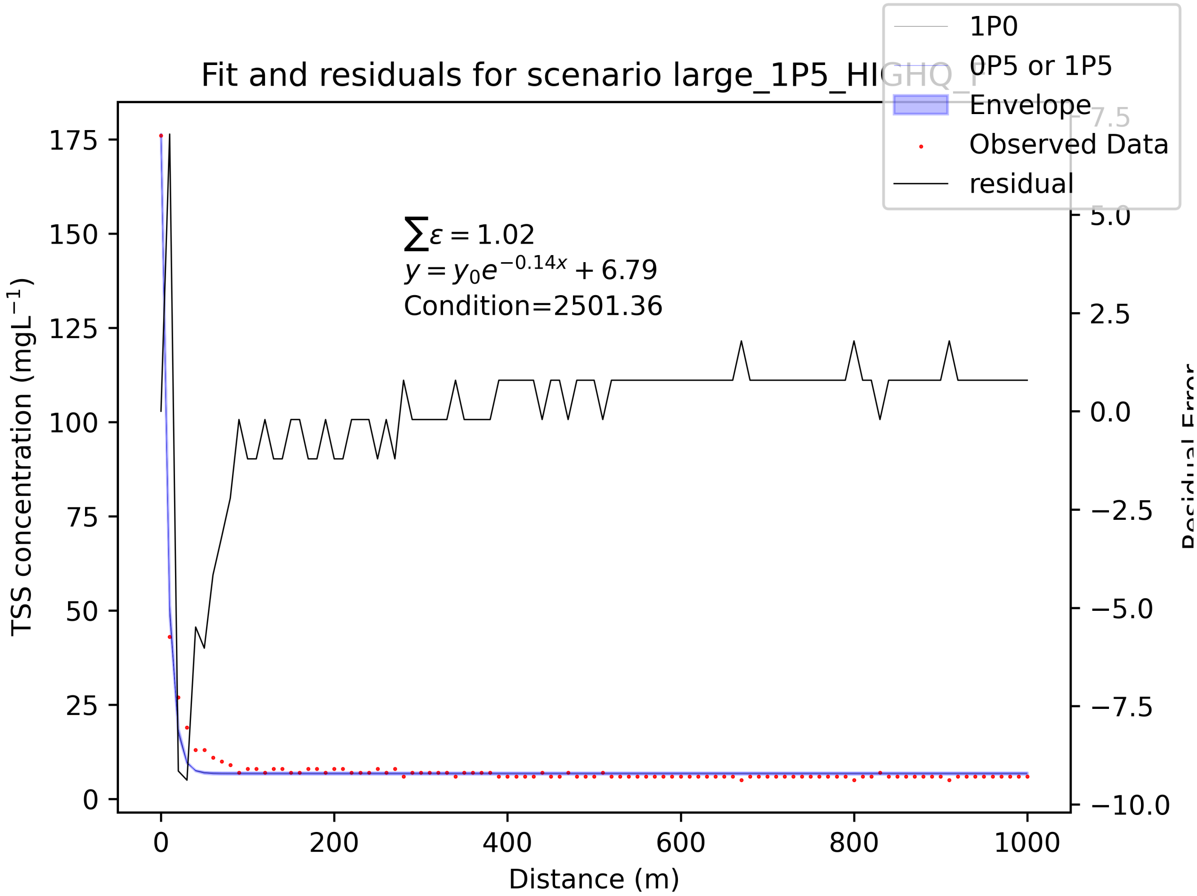

Figure 18: Fit and residual for the scenario with large stream size, 150% loading, and fine sediment with high flow.

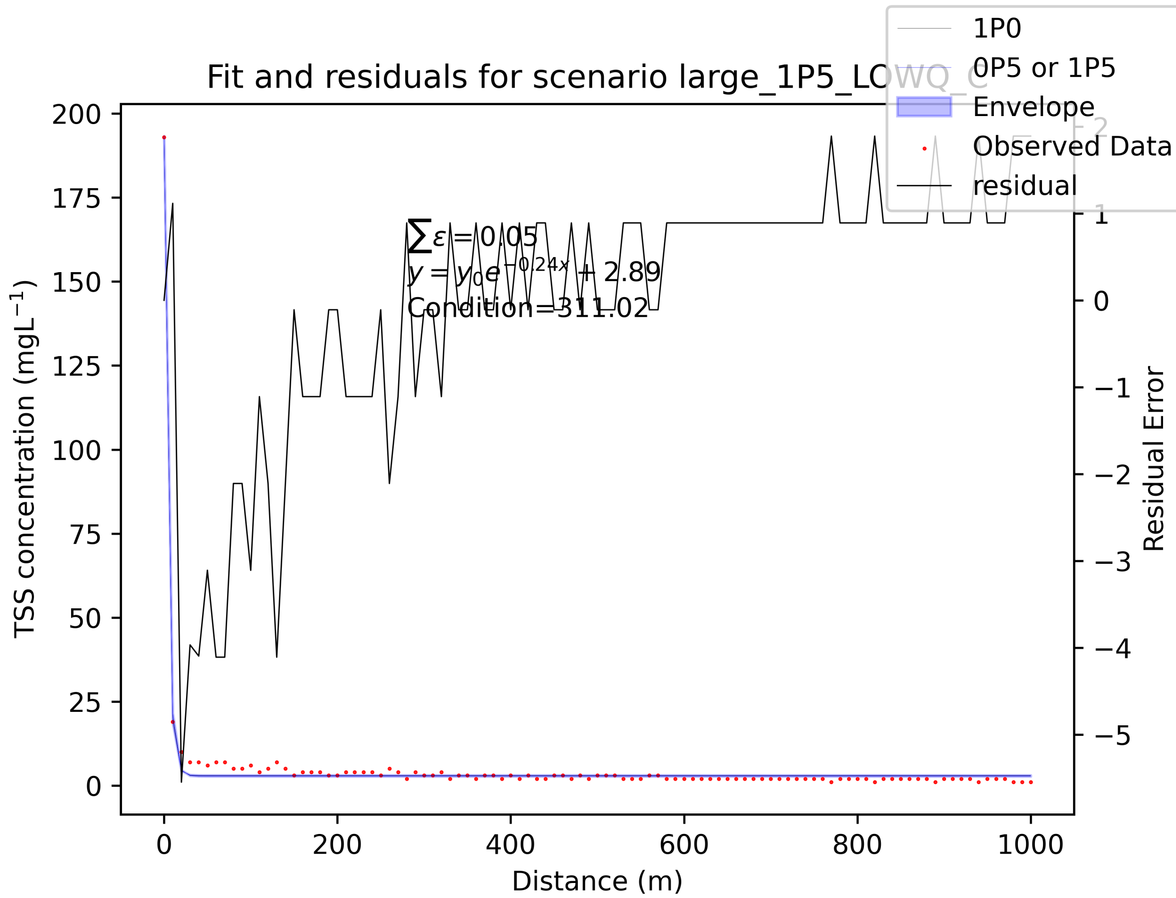

Figure 19: Fit and residual for the scenario with large stream size, 150% loading, and coarse sediment with low flow.

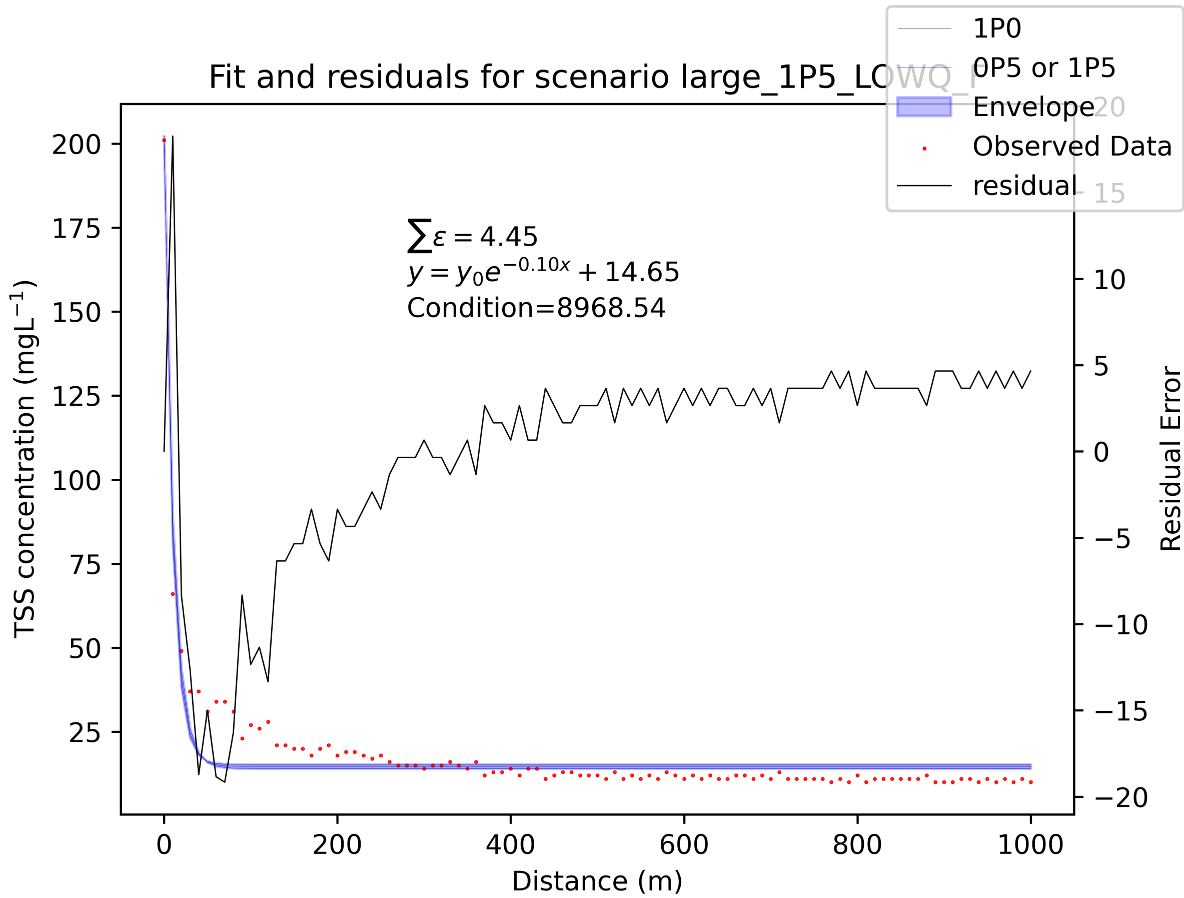

Figure 20: Fit and residual for the scenario with large stream size, 150% loading, and fine sediment with low flow.

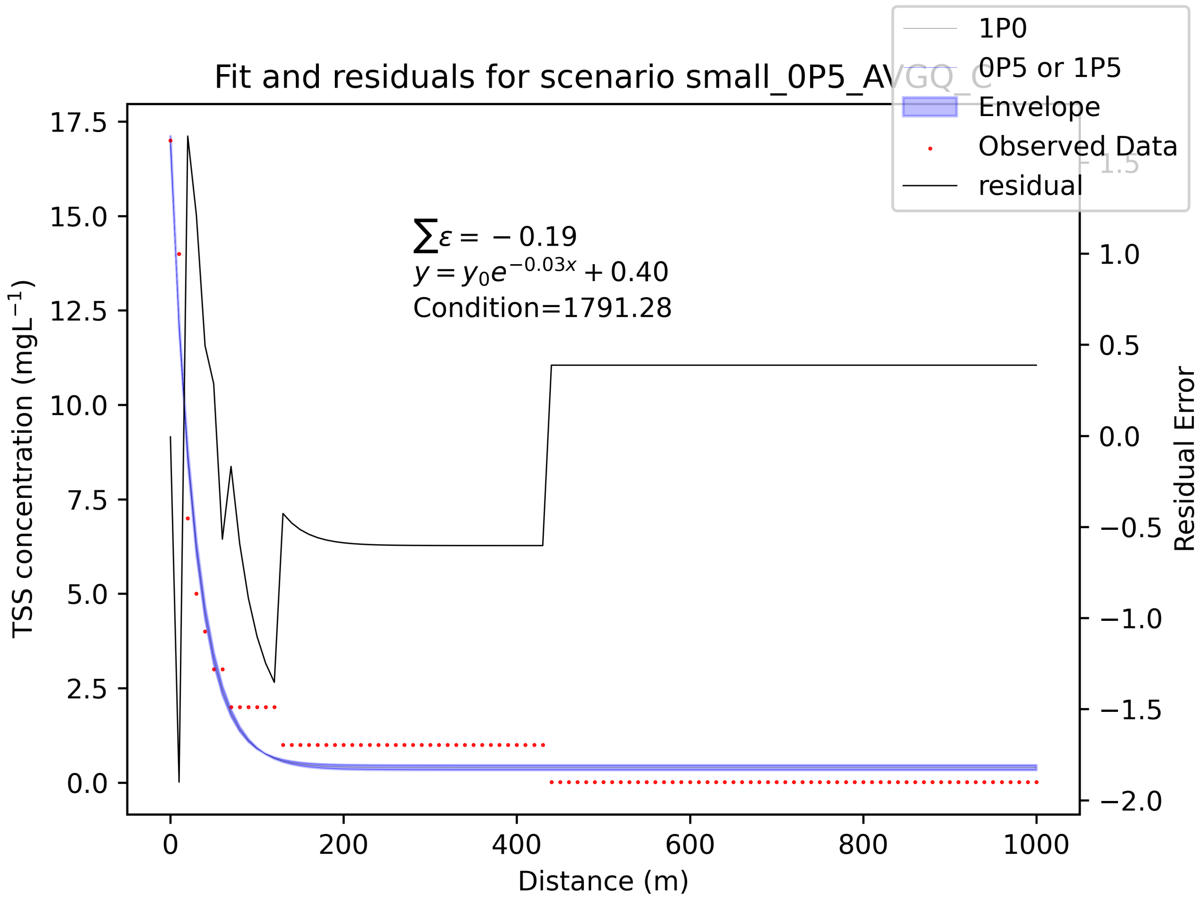

Figure 21: Fit and residual for the scenario with small stream size, 50% loading, and coarse sediment with average flow.

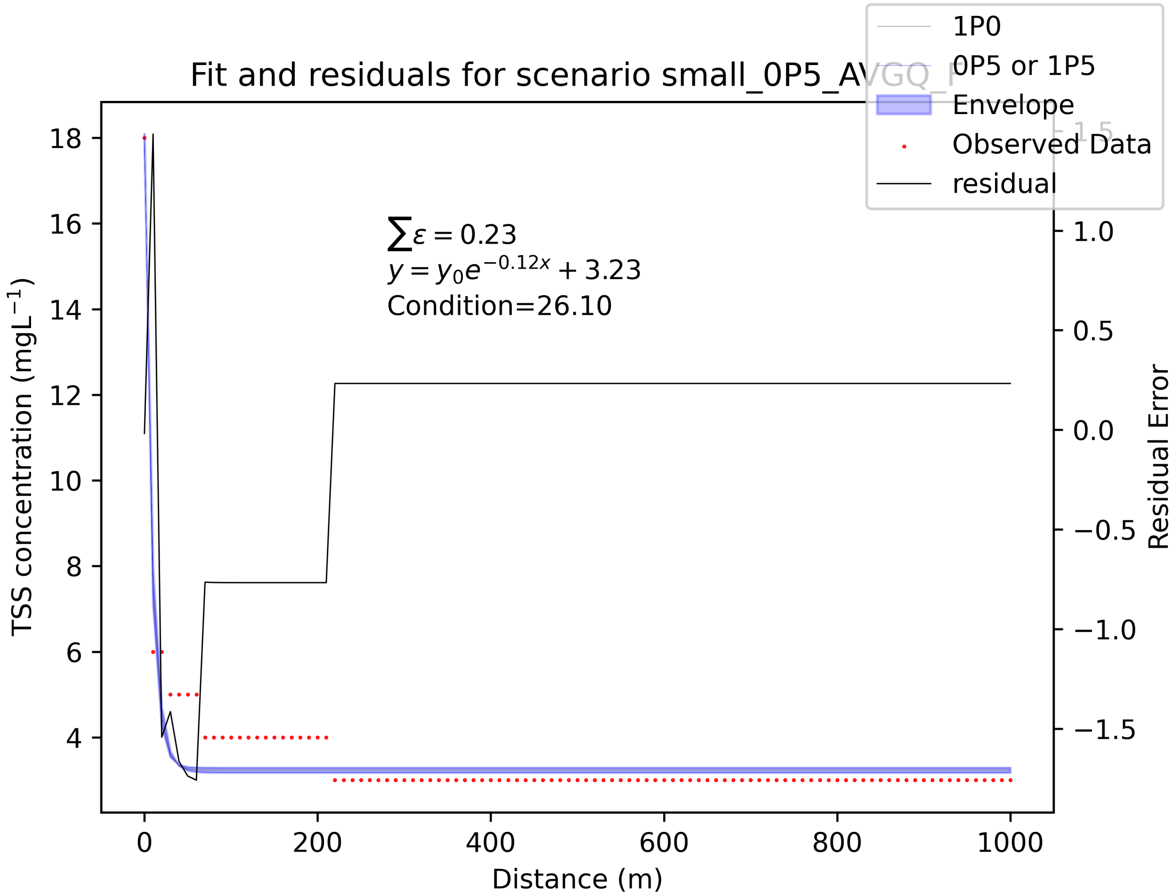

Figure 22: Fit and residual for the scenario with small stream size, 50% loading, and fine sediment with average flow.

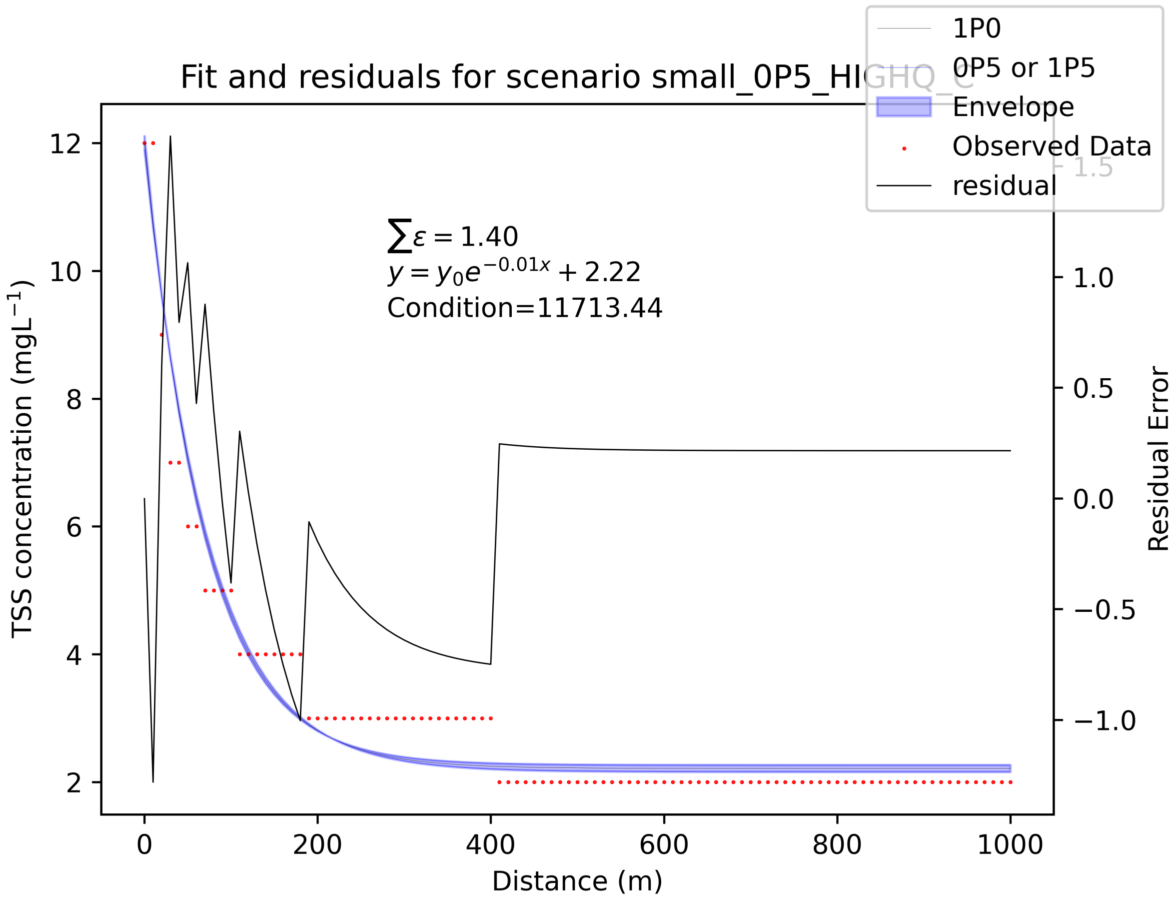

Figure 23: Fit and residual for the scenario with small stream size, 50% loading, and coarse sediment with high flow.

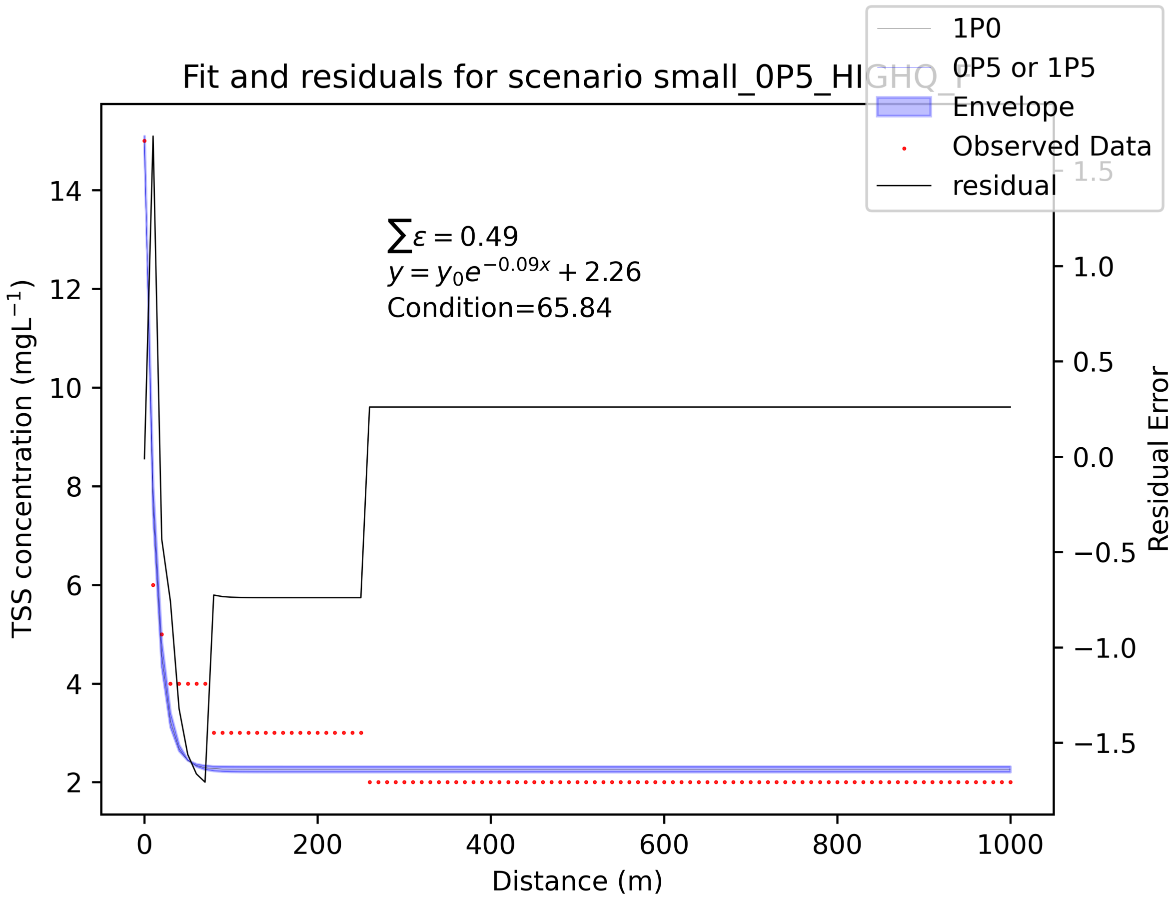

Figure 24: Fit and residual for the scenario with small stream size, 50% loading, and fine sediment with high flow.

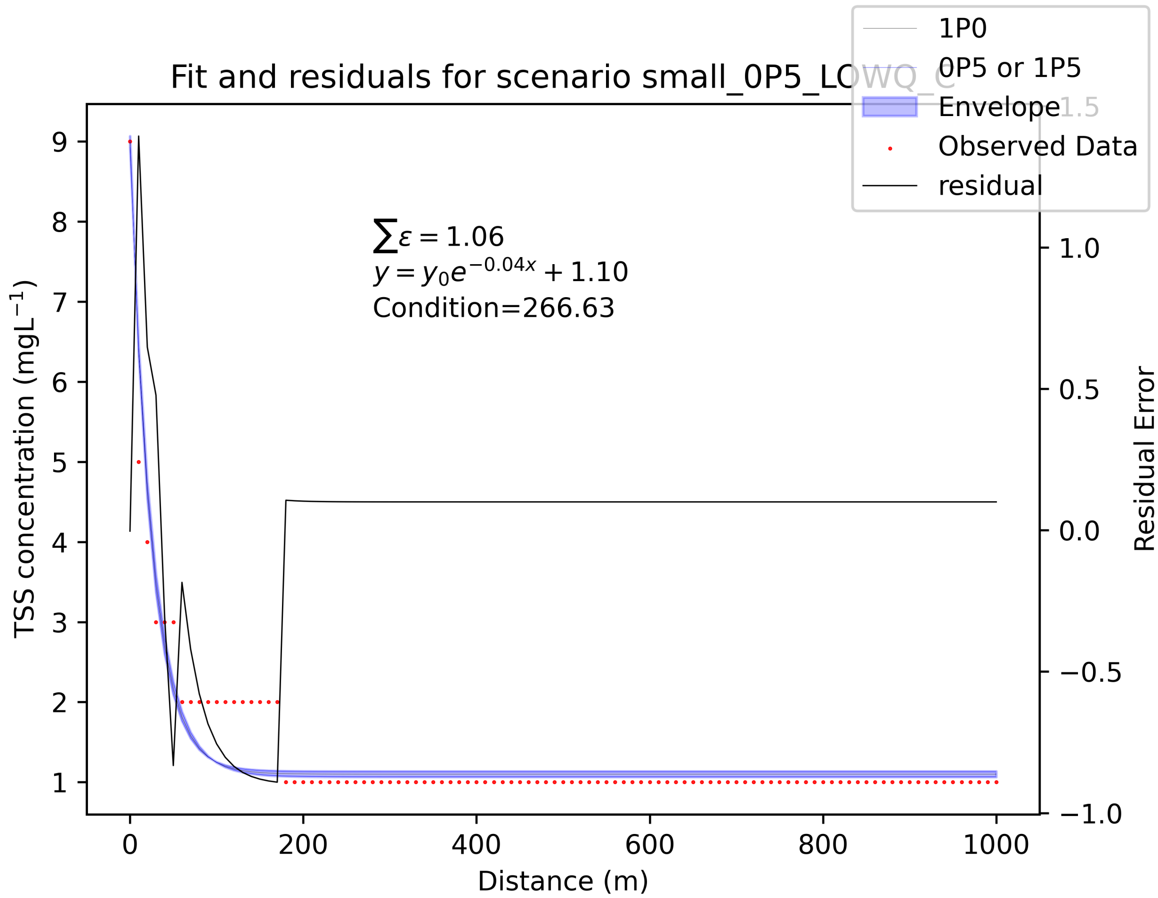

Figure 25: Fit and residual for the scenario with small stream size, 50% loading, and coarse sediment with low flow.

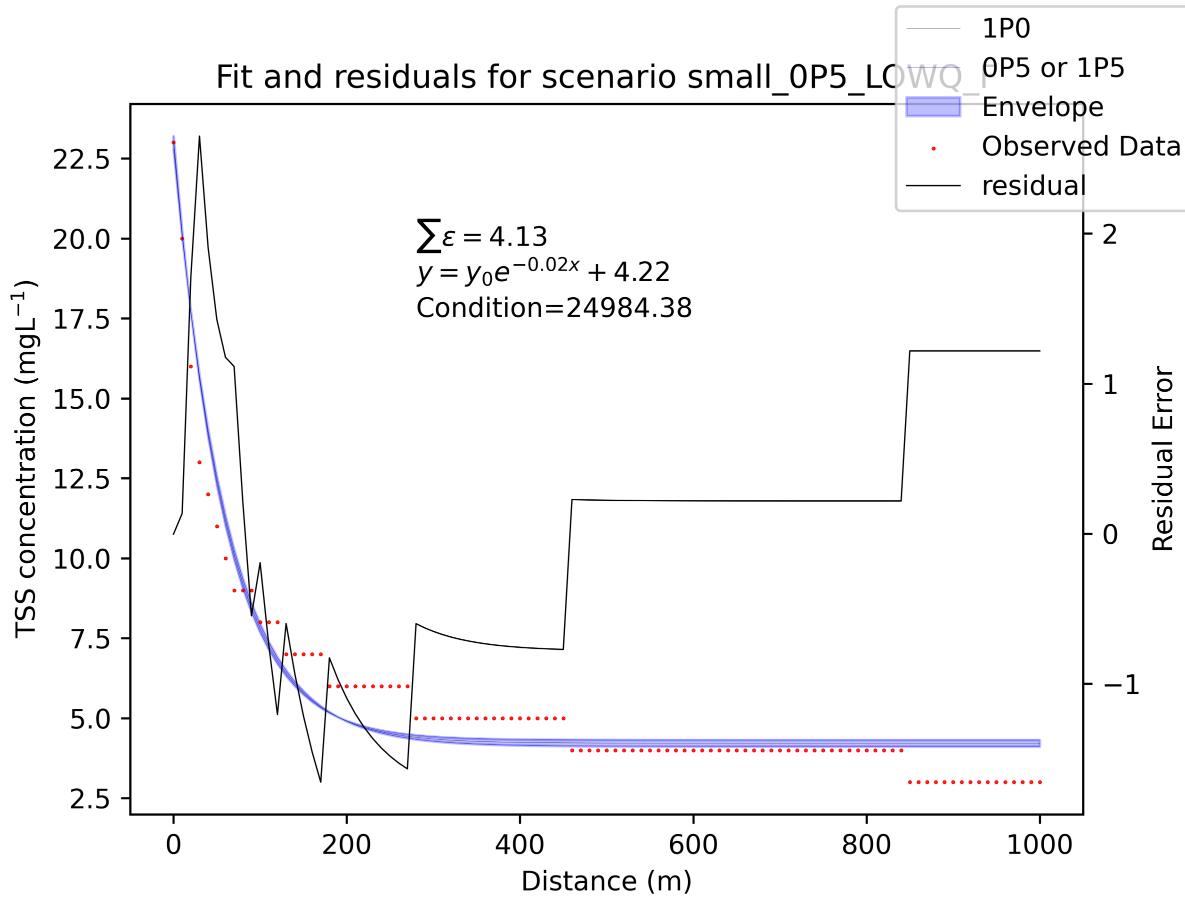

Figure 26: Fit and residual for the scenario with small stream size, 50% loading, and fine sediment with low flow.

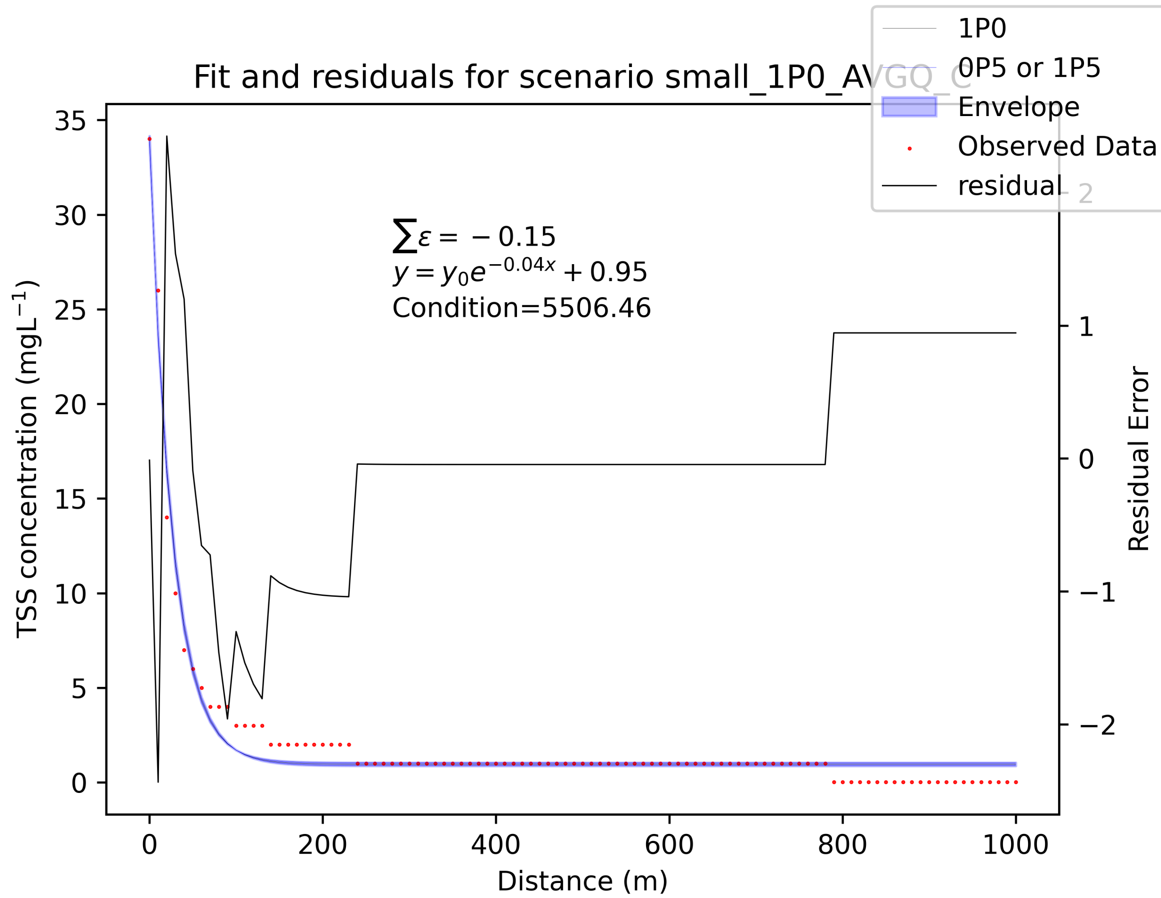

Figure 27: Fit and residual for the scenario with small stream size, 100% loading, and coarse sediment with average flow.

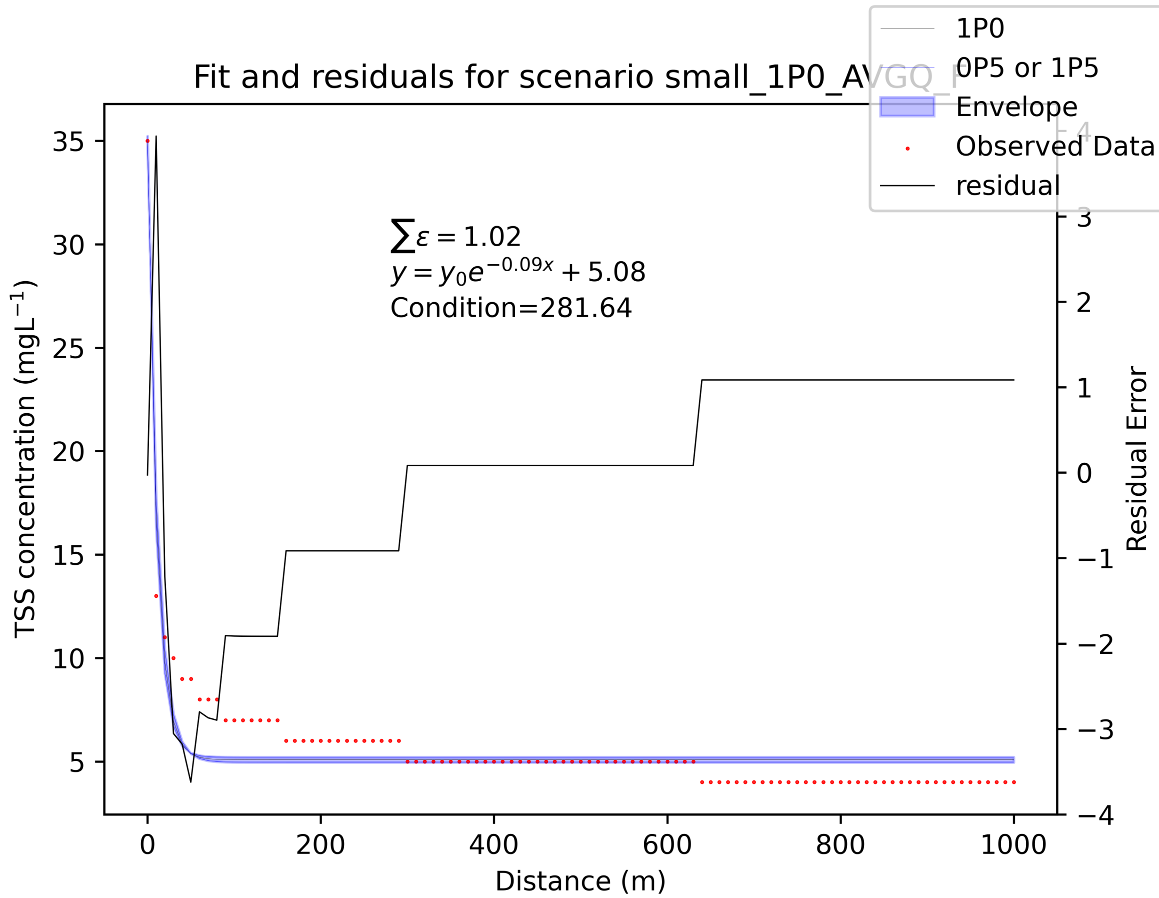

Figure 28: Fit and residual for the scenario with small stream size, 100% loading, and fine sediment with average flow.

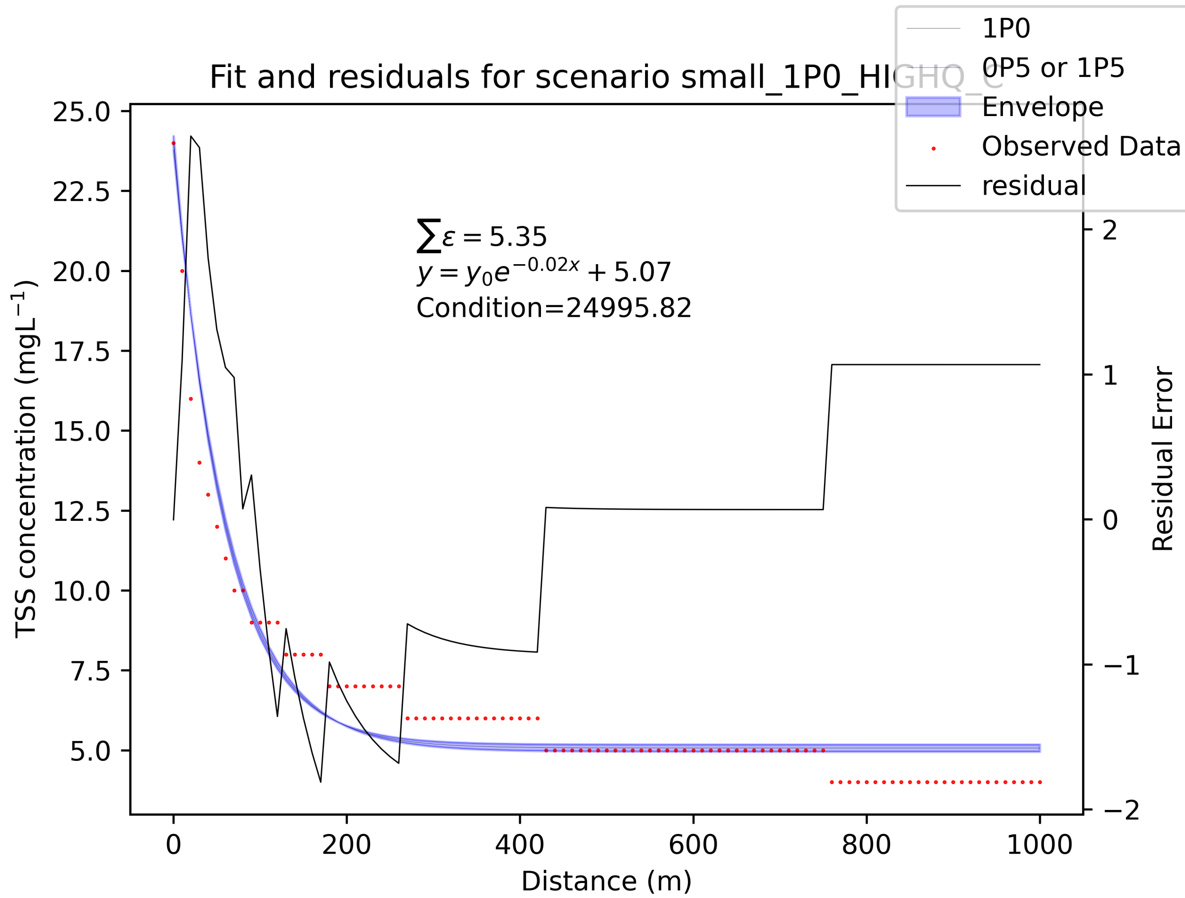

Figure 29: Fit and residual for the scenario with small stream size, 100% loading, and coarse sediment with high flow.

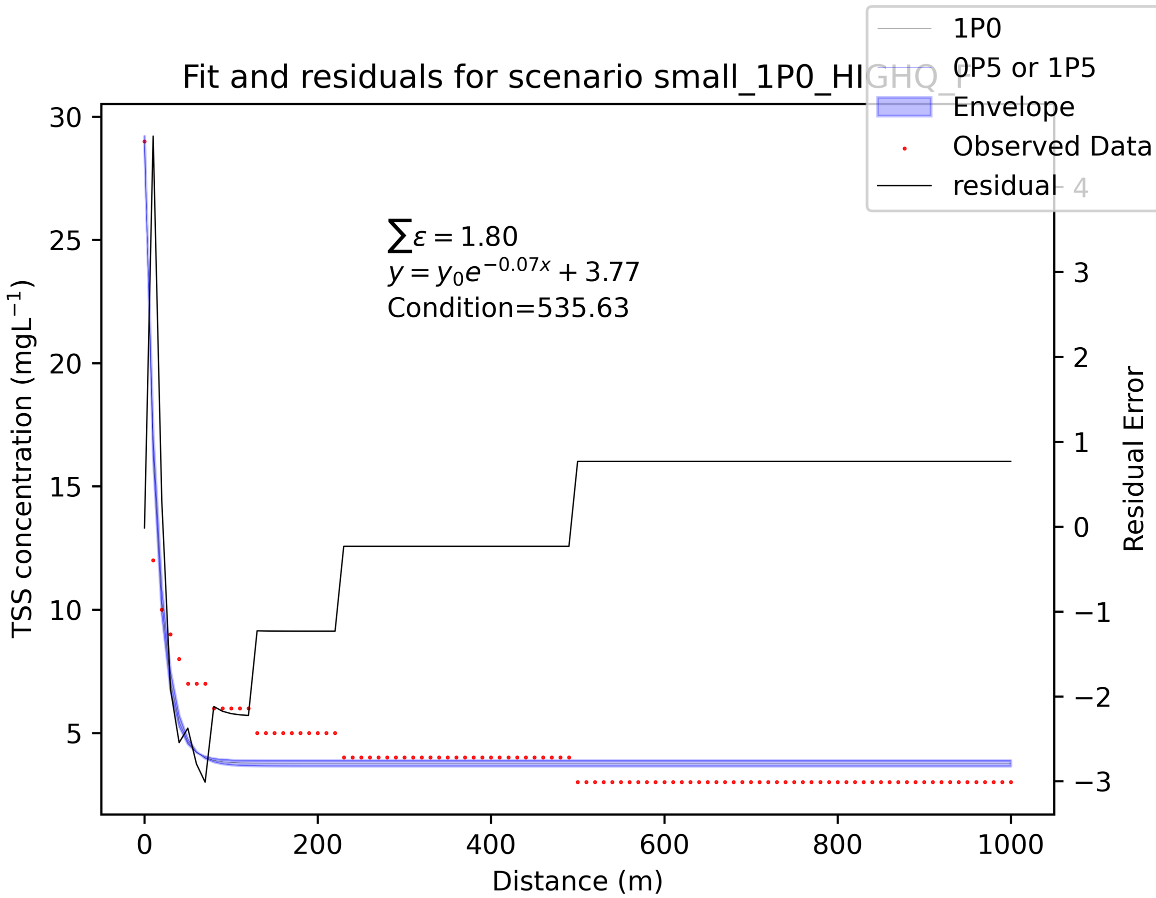

Figure 30: Fit and residual for the scenario with small stream size, 100% loading, and fine sediment with high flow.

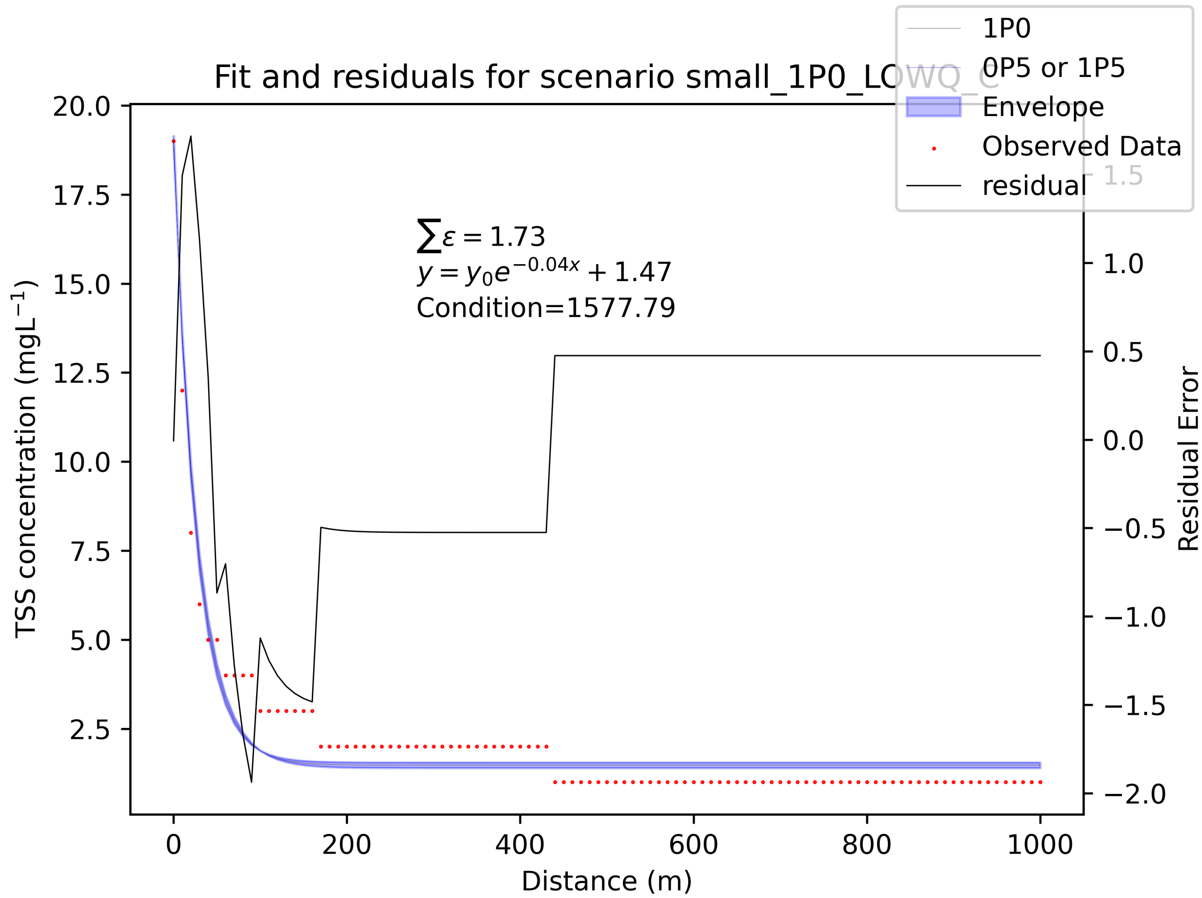

Figure 31: Fit and residual for the scenario with small stream size, 100% loading, and coarse sediment with low flow.

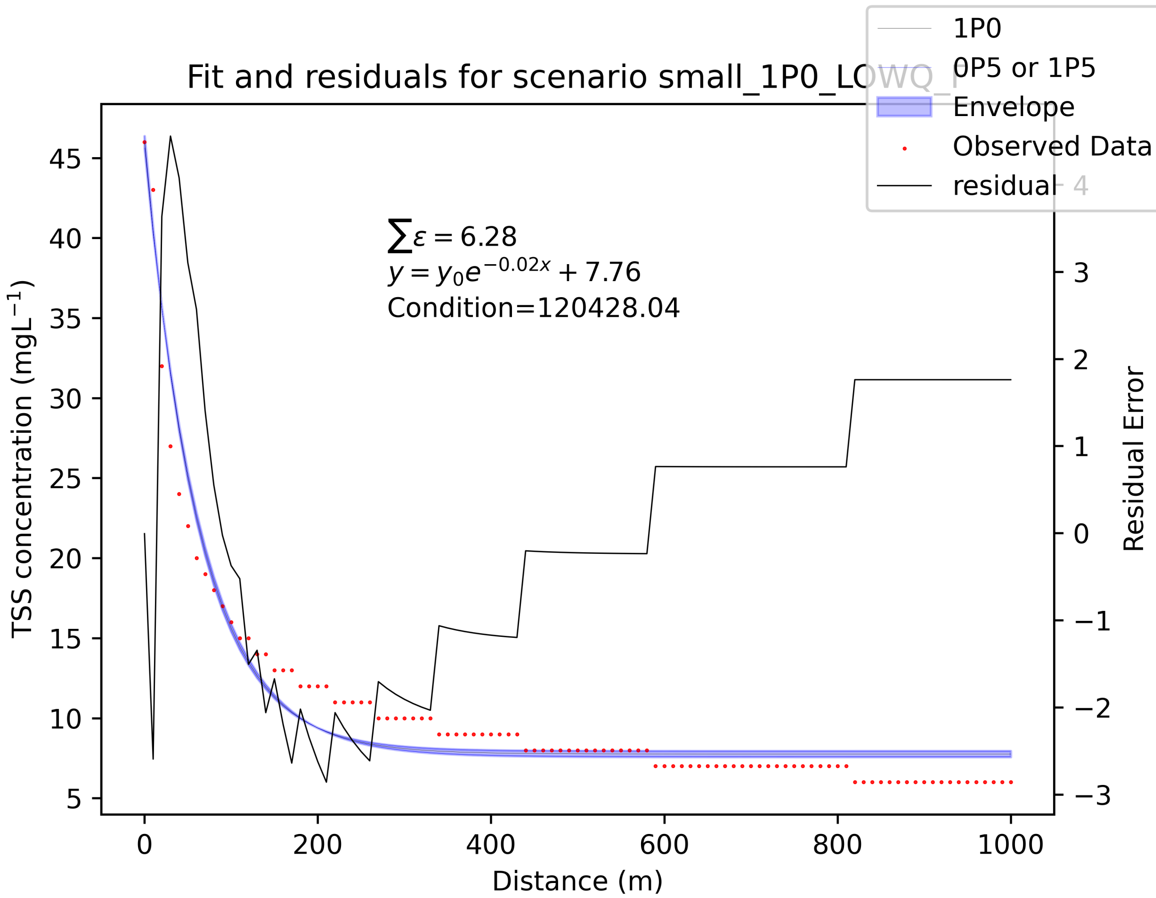

Figure 32: Fit and residual for the scenario with small stream size, 100% loading, and fine sediment with low flow.

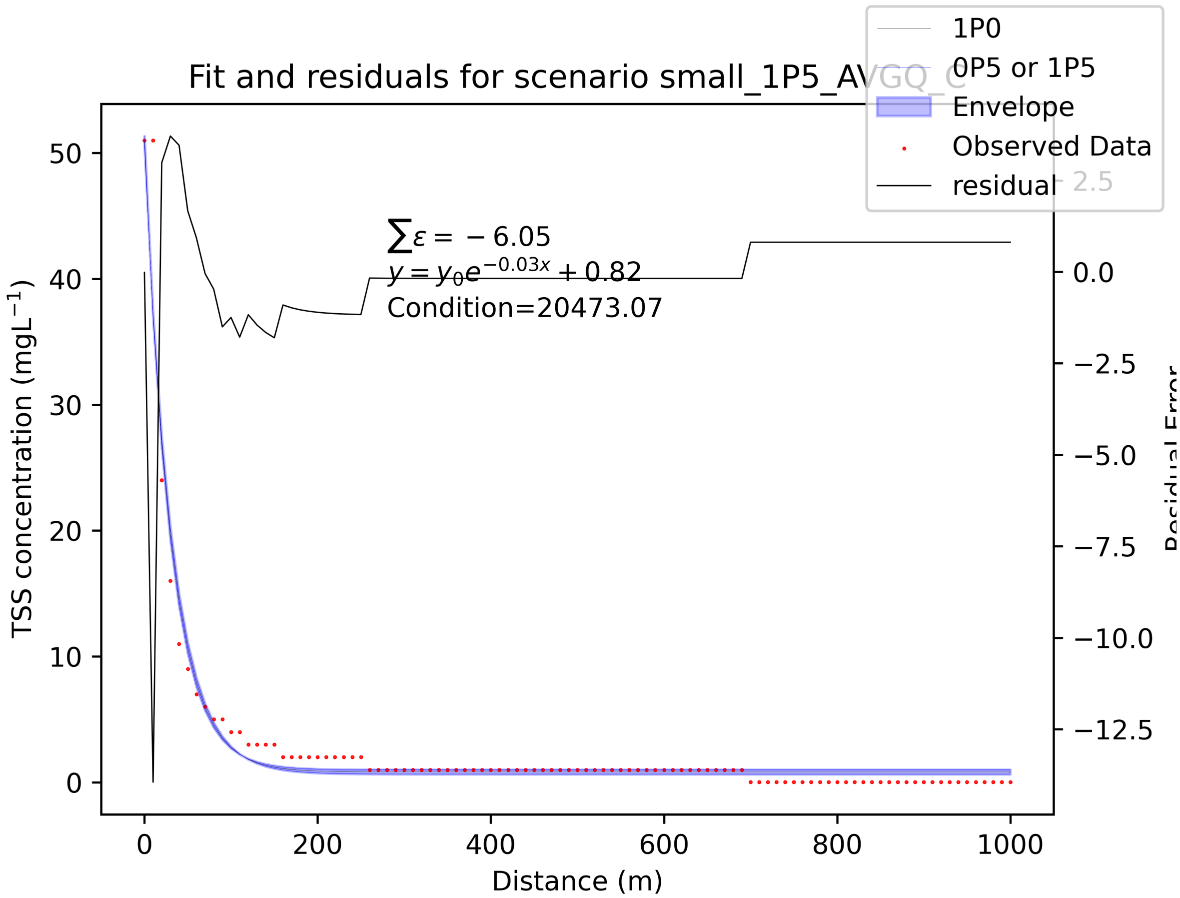

Figure 33: Fit and residual for the scenario with small stream size, 150% loading, and coarse sediment with average flow.

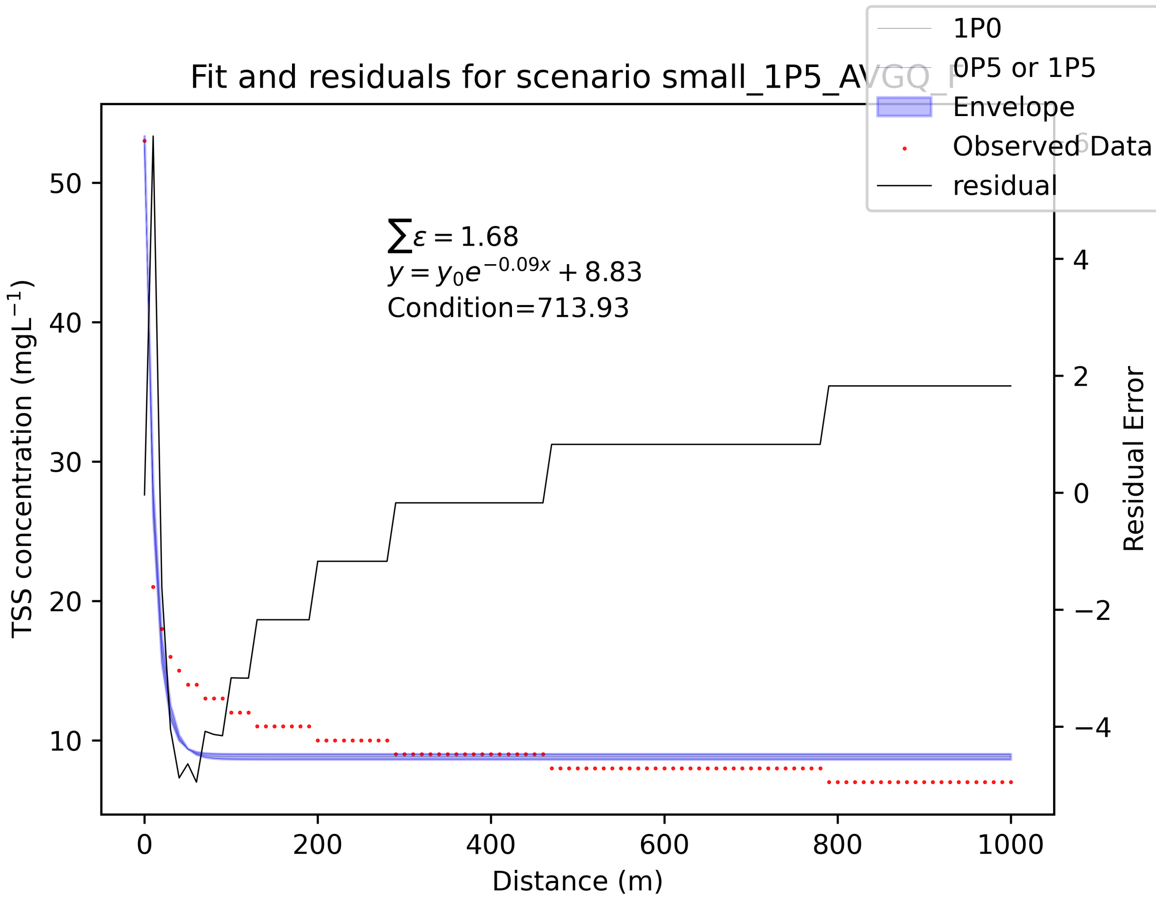

Figure 34: Fit and residual for the scenario with small stream size, 150% loading, and fine sediment with average flow.

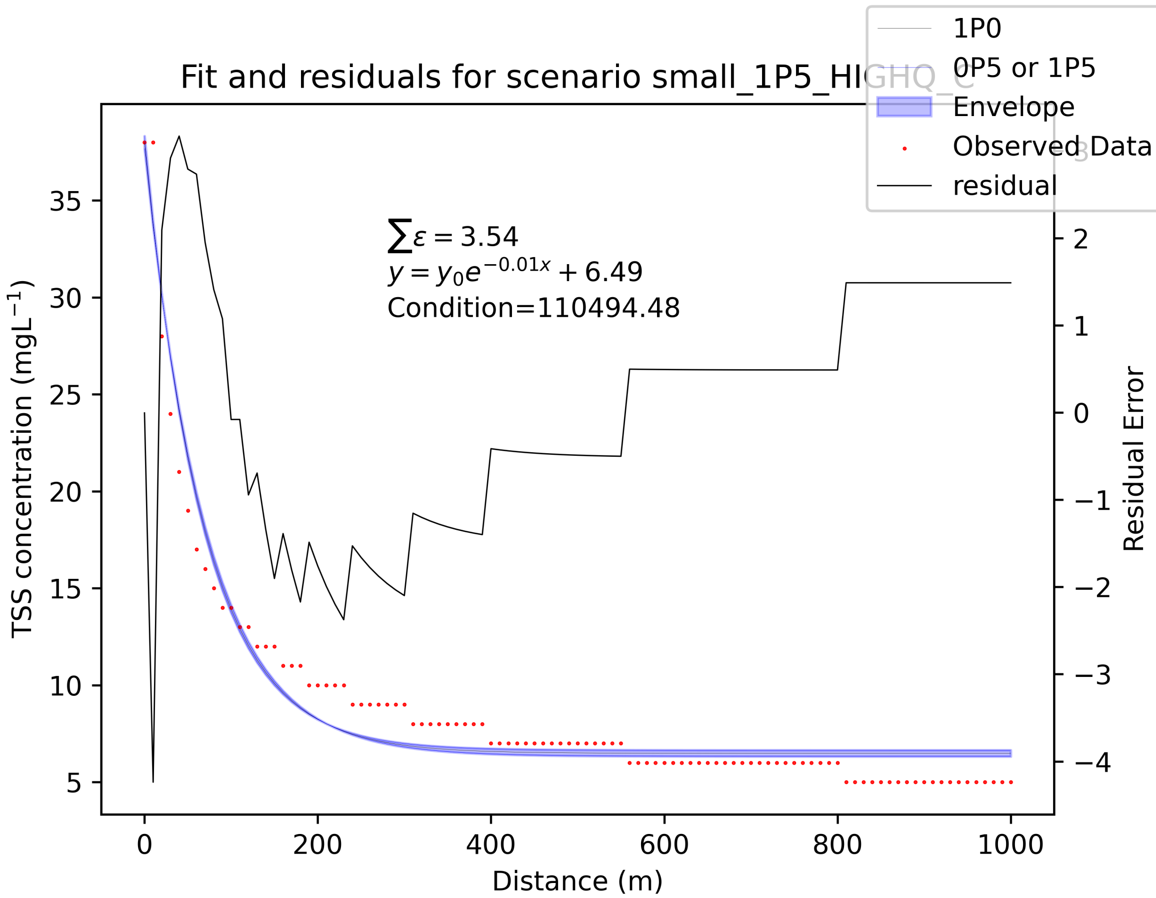

Figure 35: Fit and residual for the scenario with small stream size, 150% loading, and coarse sediment with high flow.

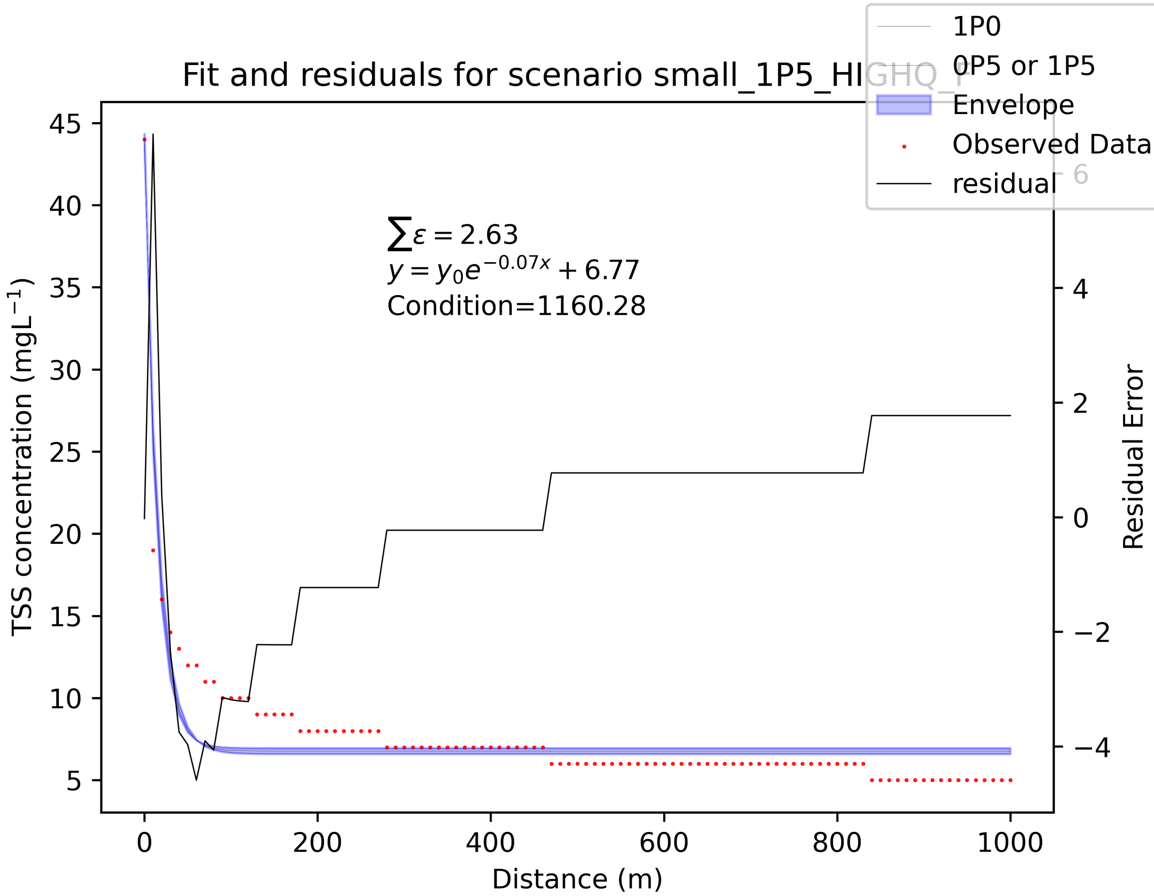

Figure 36: Fit and residual for the scenario with small stream size, 150% loading, and fine sediment with high flow.

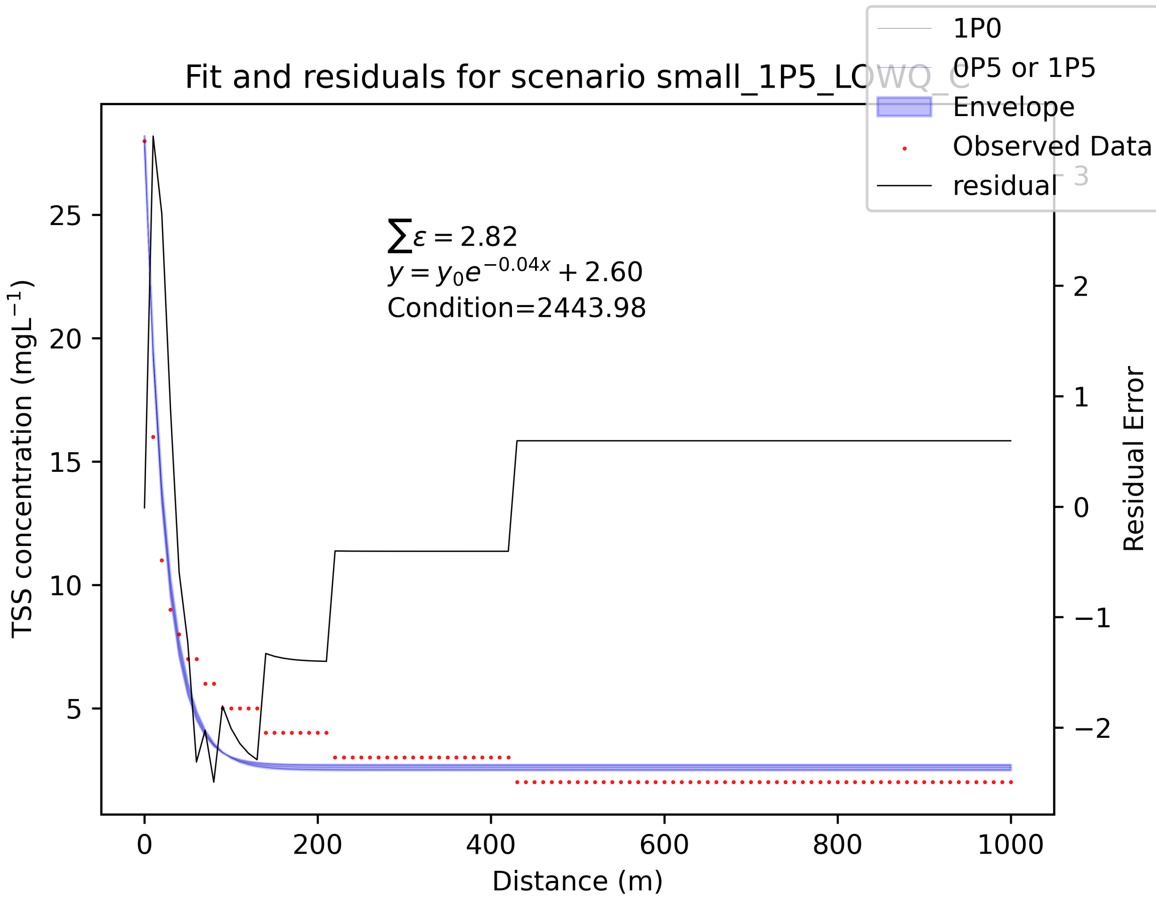

Figure 37: Fit and residual for the scenario with small stream size, 150% loading, and coarse sediment with low flow.

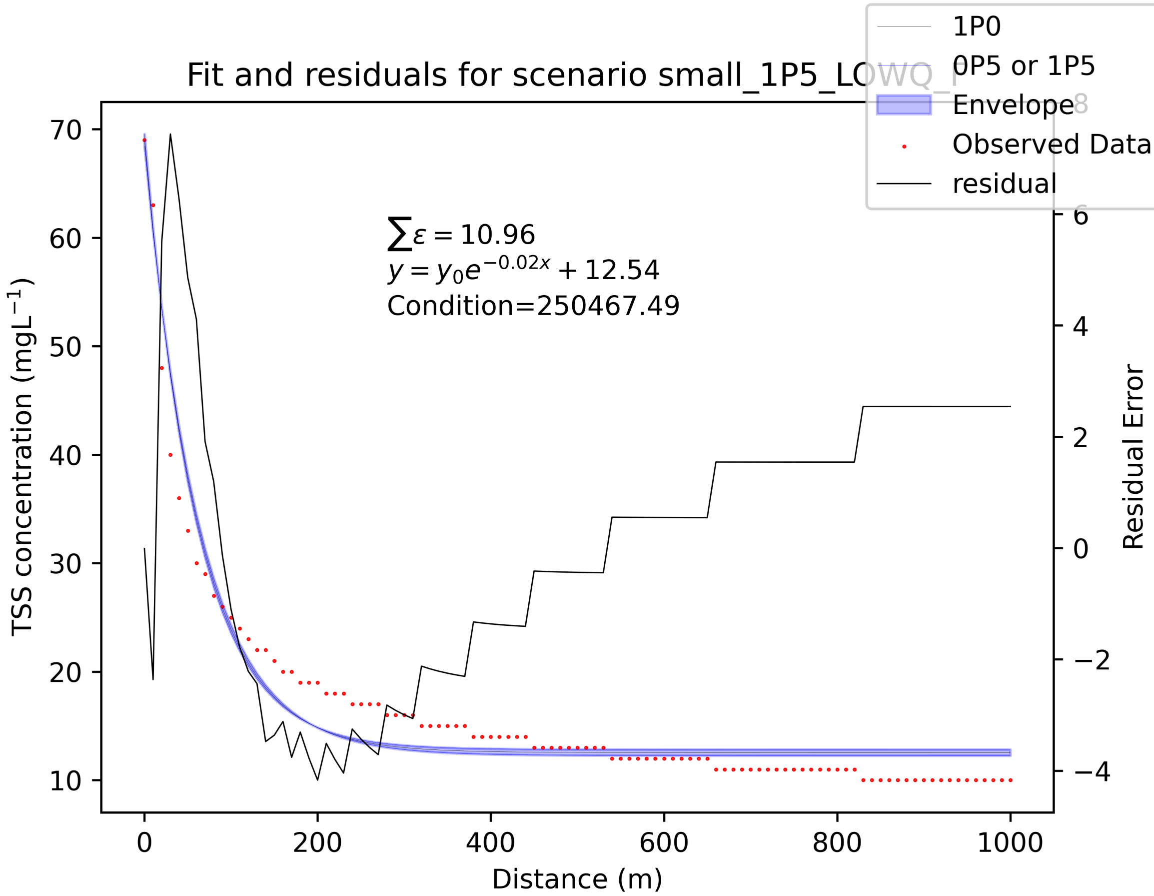

Figure 38: Fit and residual for the scenario with small stream size, 150% loading, and fine sediment with low flow.

Bibliography

Johnson, b. H., Anderson, E., Isaji, T., Teeter, A. M., & Clarke, D. G. (2000, April). *Description of the SSFATE Numerical Modeling System*. Engineer Research & Development Center. https://erdc-library.erdc.dren.mil/items/81b728f7-76c6-4ef8-e053-411ac80adeb3

Swanson, J., Isaji, T., & Galagan, C. (2007). https://www.westerndredging.org/phocadownload/ConferencePresentations/2007_WODA_Florida/Session7C-DredgingAndResuspension/6%20-%20Swanson%20-%20Fate%20of%20Dredge-Induced%20Suspended%20Sediment%20Transport%20and%20Deposition.pdf