Development of Performance Curves for Partial Sewer Separation through Sewer Deflection

Subtask 3B Technical Memorandum: Development of, and Modeling Approach for Conceptual Generic Representation of City of Cambridge, MA sewer deflection devices

Performance Curves
June 30, 2024

Prepared for:

U.S. EPA Region 1

Prepared by:

Paradigm Environmental

Great Lakes Environmental Center, Inc.

Blanket Purchase Agreement: BPA-68HE0123A0001
Requisition Number: PR-R1-23-00250
Order: 68HE0123F0056
QA Tracking Number: QA# 24009

Table of Contents

Figures

Tables

1 INTRODUCTION

Combined sewers have posed a persistent challenge to the attainment of water quality objectives, particularly when storm events cause overflow of sanitary and stormwater pollutant loads to waters of the United States (i.e., Combined Sewer Overflows (CSO)). To address this issue, substantial investments, amounting to billions of dollars, have been made to entirely separate sanitary and storm sewers to prevent CSOs. While these investments have made considerable progress in cleaning up local waterways, stormwater pollution continues to cause water quality impairments.

The City of Cambridge, Massachusetts (MA) has introduced a strategy known as "Sewer Deflection" or partial sewer separation. This approach involves diverting a portion of stormwater *back to* an existing combined sewer (CS) for discharge to Boston's Deer Island Wastewater Treatment Plant [1] (in the City, not all CS have been separated; the remaining existing CSs function as sanitary sewers discharging to Deer Island for treatment). Stormwater not diverted to the treatment plant is discharged to receiving waters without additional treatment.

Assuming continued use of CSs can somehow avoid CSOs and other potential barriers (e.g., law, administration), the cost-benefit objective of this strategy is noteworthy: if a small portion of stormwater can be discharged back to a CS without causing a CSO, the result is an offset of what (i.e., the first flush) would otherwise represent a substantial cost associated with the design and implementation of stormwater controls within the City's geographically constrained urban areas (assuming implementation feasibility). However, there is a cost for the treatment of sanitary discharge to Deer Island that needs to be included in the cost calculation. The volume of discharge from an outfall can be significant, meaning the volume diverted can also be significant: diverting too much stormwater to Deer Island can result in appreciable costs. Consequently, the engineering and cost-benefit objective is to maximize the treatment of stormwater pollutant load while minimizing the volumetric discharge to the CS.[2]

This project develops a generic representation of the City's diversion device which allows for the development of generic pollution reduction curve(s) similar to those already featured in Appendix F of the 2016 Massachusetts and 2017 New Hampshire Municipal Separate Storm Sewer System (MS4) permits. By examining the relationships between discharge volume as a function of both orifice diameter and weir height/depth, it may be possible to optimize stormwater pollutant load treatment while minimizing the volumetric diversion to a treatment facility, and thereby cost. From a regulatory standpoint, this would enable the City to receive credit for stormwater treatment achieved through the implementation of these deflection devices – because, despite its practicability, more widespread adoption of this practice is currently precluded due to lack of regulatory credit that the City can claim for stormwater pollution reduction under its existing MS4 permit. The performance curves developed for this project could be applied to other municipalities capable of such deflection strategies.

This Subtask 3B Technical Memorandum (TM) describes the development of long-term cumulative performance curves applicable for planning and crediting sewer deflection devices within EPA Region 1 (EPA R1). The work described in this TM is based on previous work completed under Task 3A to configure and calibrate an existing deflection device in Cambridge, MA within EPA R1's Opti-Tool (Paradigm Environmental, 2024). The calibrated Opti-Tool for Sewer Deflection device was used to create performance curves for 5 pollutants (TP, TN, TSS, Zn, and Bacteria) as well as flow volume diversion using the influent timeseries of HRU runoff and stormwater quality based on Boston, MA climatic data for 31 years (Jan 1992 – Dec 2022). The results of this TM consist of 44 sets of performance curves, each including 6 curves for flow and 5 modeled pollutants. These sets represent various deflection device configurations, such as varying

[1] Refer to https://www.bostonharborislands.org/deer-island/

[2] It is interesting to note the volumetric capacity of a sanitary sewer of smaller diameter would prohibit such a strategy because only the CS has the volumetric capacity for accommodating such stormwater flow/volume.

diversion orifice size, weir height, and slope (for scenarios where there is no weir). The summary section guides how to apply these curves.

2 CITY OF CAMBRIDGE'S TALBOT DEFLECTION DEVICE

The City of Cambridge's Talbot deflection device was modeled to develop a generic deflection device representation in the Opti-Tool, as described in the Task 3A memo (Paradigm Environmental, 2024). Details on this existing deflection device, including GIS datasets of the pipe networks and drainage area, as-built specifications, and observed outfall flow time series, were provided by the City of Cambridge and their consultant, Stantec. The Talbot device (Figure 2-1) receives flow from the separated stormwater system covering most of the Talbot drainage area (Figure 2-2). This device diverts a portion of stormwater into the combined sewer system through a 6-inch orifice to an 18-inch pipe with a flap gate to prevent backflow. When the stormwater pipes flowing into the device are filled, excess water in the device not able to flow through the orifice overtops the weir and flows to the Charles River. The weir has a sliding gate that remains open under normal conditions but can be manually closed to prevent backflow from the river under extreme flood conditions. The observed outfall time series for this device is measured at the weir and represents conditions where stormwater overtopped the weir. A portion of the flow during large events, and all other flow, is assumed to be diverted to the combined sewer for treatment.

Representing the Talbot device in the Opti-Tool required calculating the area draining to the deflection device (as opposed to the area draining to the outfall at the Charles River). Based on the available GIS data (topography, pipe network) the drainage area upstream of the Talbot device was estimated using the nearby railroad tracks as a divide; this approach was confirmed by the City of Cambridge. The device drainage divide is shown in Figure 2-3.

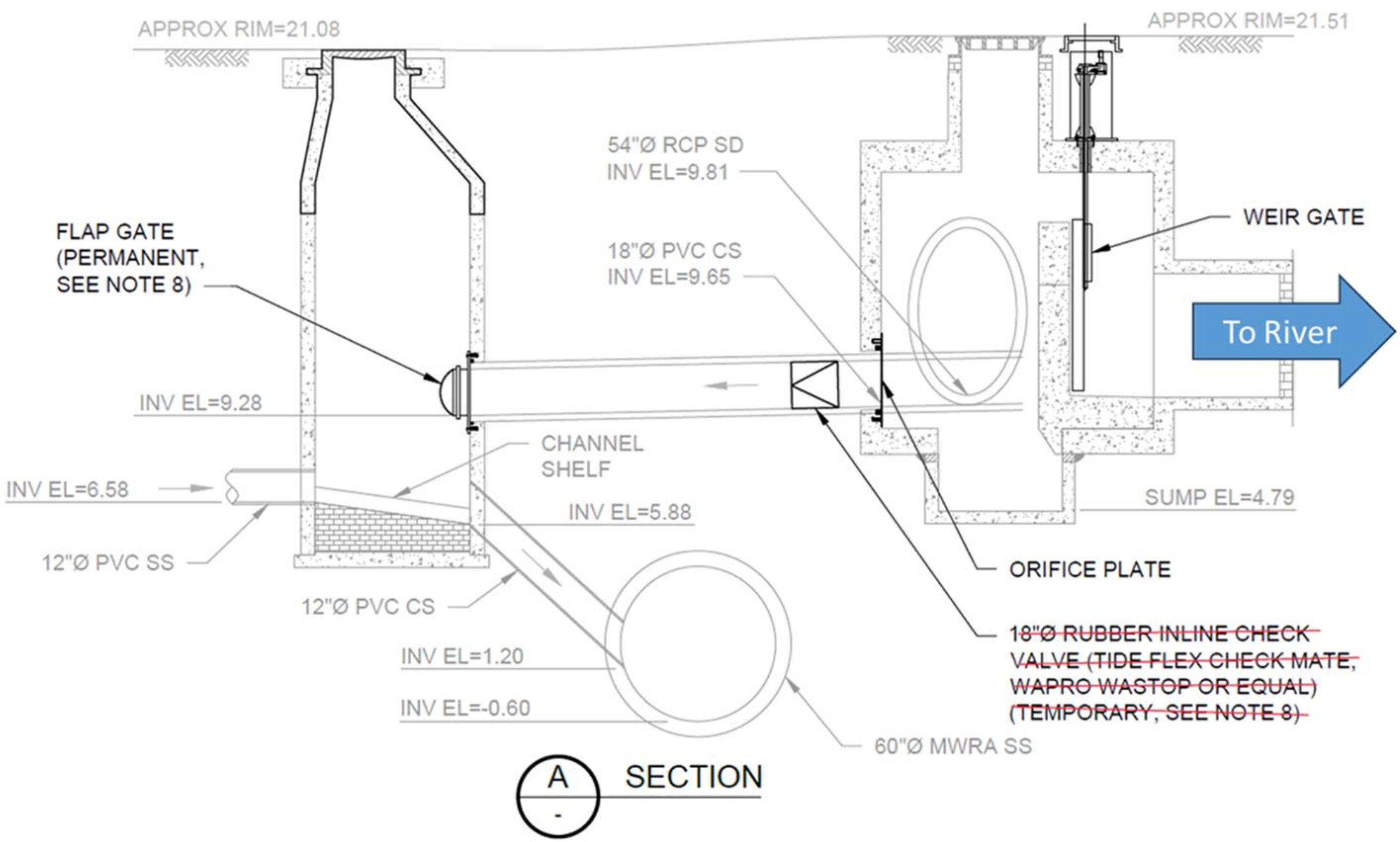

Figure 2-1. As-built specifications for the Talbot device illustrating the orifice diverting stormwater flow (right) into the combined sewer (left) (adapted from Kleinfelder and Stantec, 2020). When the volume of water in the device exceeds the weir height, excess stormwater is diverted to the Charles River.

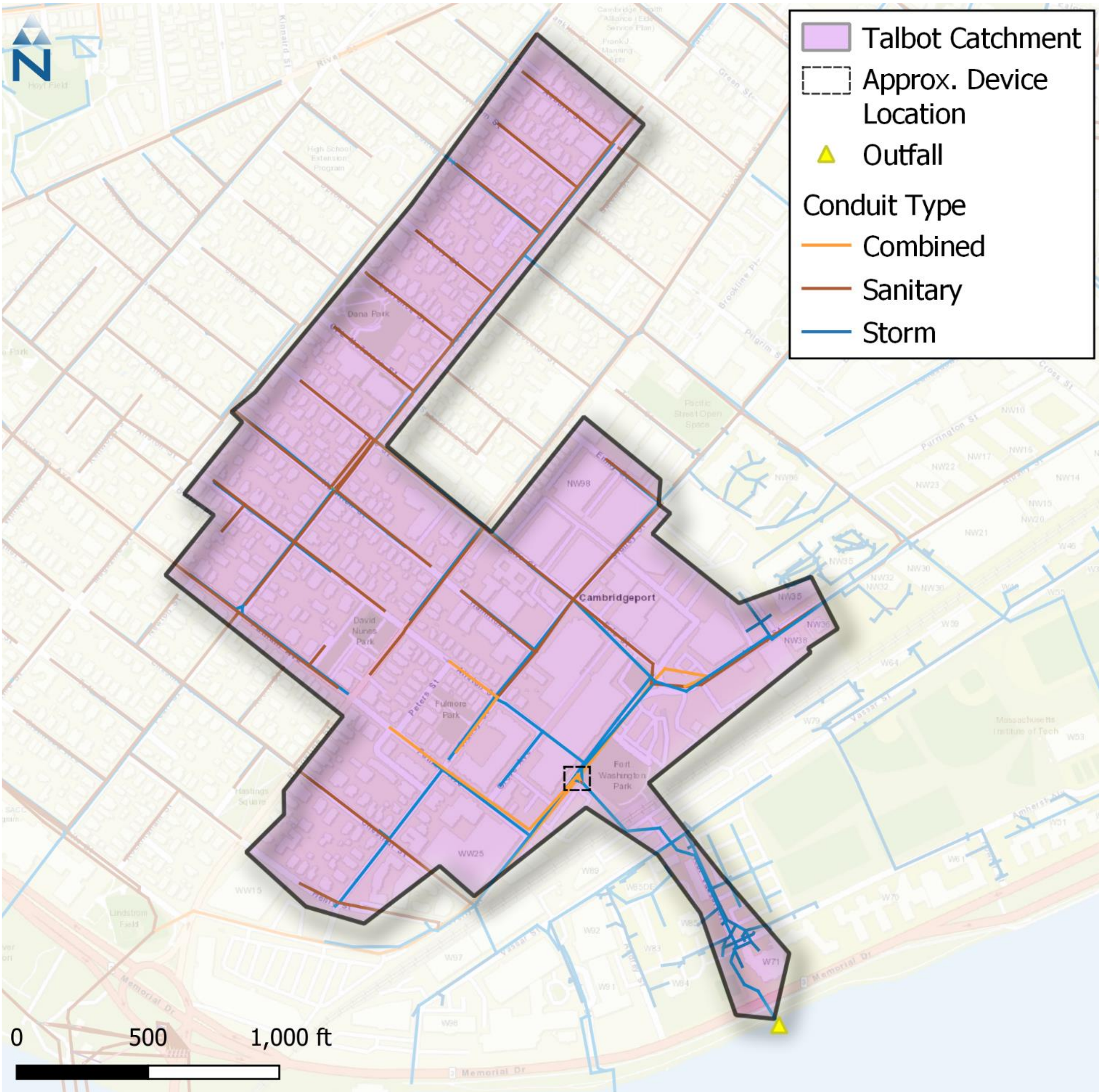

Figure 2-2. Storm sewer pipe networks and drainage catchments to Talbot outfall.

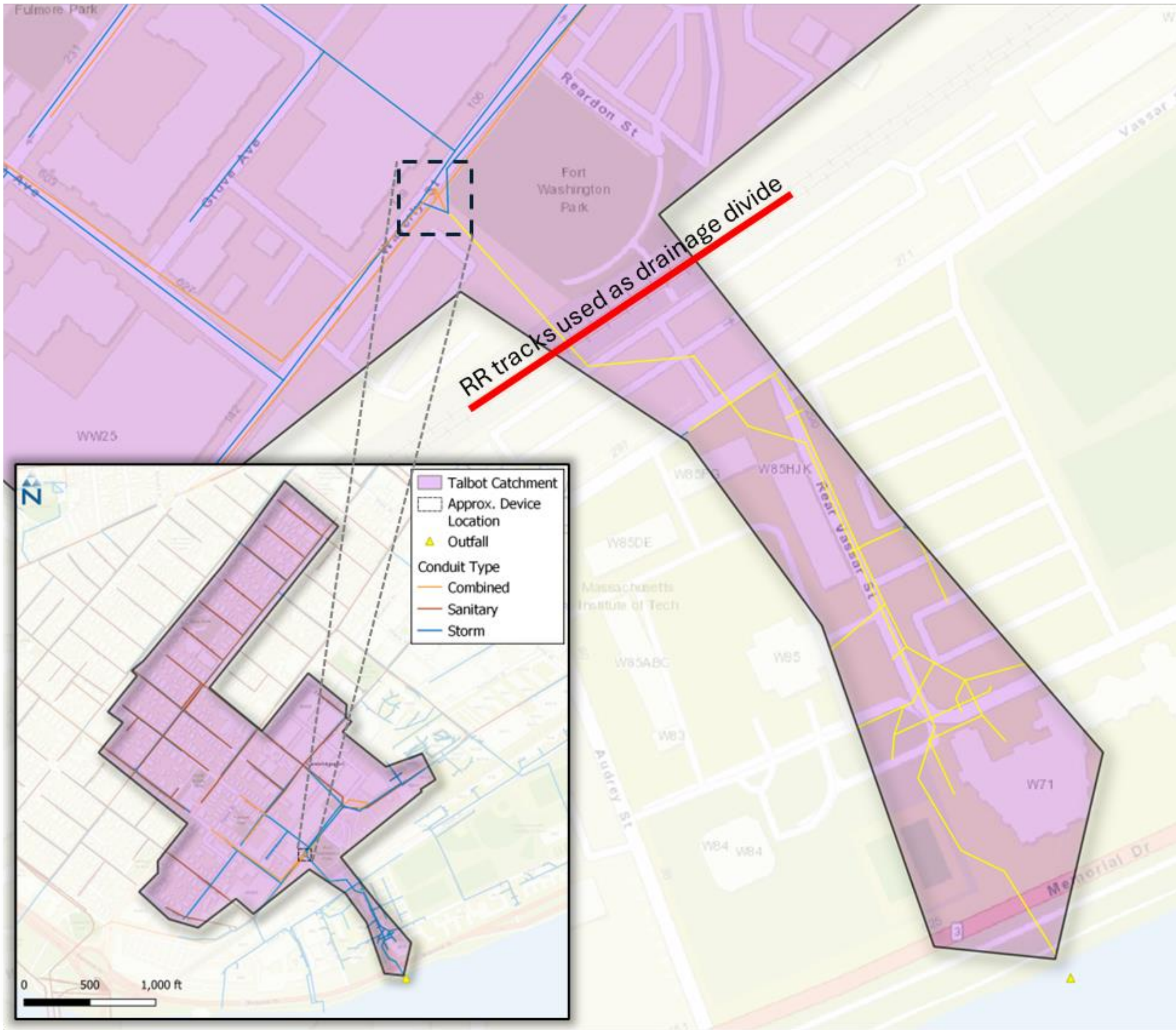

Figure 2-3. Map depicting pipes downstream (yellow) of the Talbot deflection device and the railroad tracks (red) used as a divide to approximate the device drainage area.

3 OPTI-TOOL SET UP

To create performance curves, the Talbot device was configured and calibrated within the Opti-Tool as detailed in the Task 3A memo (Paradigm Environmental, 2024). This configuration required several inputs and processes which are briefly outlined in the following subsections and include:

1. GIS analysis to create Opti-Tool Hydrologic Response Units (HRUs) that characterize stormwater flow and pollutant loading for the Talbot drainage area.
2. Creation of HRU time series using the Opti-Tool SWMM model and local meteorological data.
3. Configuration of the deflection device's physical characteristics using the Opti-Tool Regulator stormwater control measure (SCM; often referred to as a Best Management Practice [BMP]).
4. Calibrating the Opti-Tool deflection device to match the estimated diverted flow volume of 90% for the 1992 typical year[3] as calculated by the City of Cambridge and Stantec (City of Cambridge and Stantec, 2023).

3.1 Hydrologic Response Unit (HRU) Development

HRUs are used by the Opti-Tool to characterize flow and pollutant loading from the drainage area of a given SCM. A set of unique HRUs was developed for the City of Cambridge (including the Talbot drainage area) based on land use, land cover, and soil characteristics which reflect key physical features that influence hydrology and water quality. Land use describes the principal programmatic use and/or vegetation type. The programmatic, or zoning, element of this attribute is critical for water quality simulation. The land cover defines landscapes as having either pervious or impervious cover. Hydrologic Soil Groups (HSG) represent a spectrum of infiltration rates based on one of four soil classes (i.e., A, B, C, and D); HSG-A has the highest infiltration rates and HSG-D has the lowest.

The land use - land cover and HSG layers were spatially overlaid in GIS to derive a composite raster representing the unique classes in each layer. The resulting raster and attribute table were reclassified into 19 unique mapped HRUs suitable for use in the Opti-Tool. The spatial distribution of the mapped HRUs within the Talbot drainage area is detailed in Table 3-1 and shown in Figure 3-1.

[3] Typical Year Rainfall: The performance objectives of MWRA's approved Long-Term CSO Control Plan include annual frequency and volume of CSO discharge at each outfall based on "Typical Year" rainfall from 40 years of rainfall records at Logan Airport, 1949-1987 plus 1992. The Typical Year was a specifically constructed rainfall series based primarily on a single year (1992) close to the 40-year average in total rainfall and distribution of rainfall events of different sizes. The rainfall series was adjusted by adding and subtracting certain storms to make the series closer to the actual averages in annual precipitation, the number of storms within different depth ranges, and storm intensities. The development of the Typical Year is described in MWRA's System Master Plan Baseline Assessment, June 15, 1994. The Typical Year consists of 93 storms with a total precipitation of 46.8 inches.

Table 3-1. HRU distribution for the Talbot device drainage area

HRU ID	HRU Name	Cover Type	Hydrologic Soil Group	Area	
				Acre	%
1000	PavedAgriculture-IMP	Impervious	N/A	--	--
2000	PavedCommercial-IMP	Impervious	N/A	5.18	6.23%
3000	PavedDevelopedOpenSpace-IMP	Impervious	N/A	0.83	1.00%
4000	PavedForest-IMP	Impervious	N/A	--	--
5000	PavedHighDensityResidential-IMP	Impervious	N/A	35.84	43.07%
6000	PavedIndustrial-IMP	Impervious	N/A	13.11	15.76%
7000	PavedLowDensityResidential-IMP	Impervious	N/A	--	--
8000	PavedMediumDensityResidential-IMP	Impervious	N/A	--	--
9000	PavedTransportation-IMP	Impervious	N/A	11.91	14.32%
10200	Agriculture-B	Pervious	B	--	--
11100	DevelopedOpenLand-A	Pervious	A	14.47	17.40%
11200	DevelopedOpenLand-B	Pervious	B	--	--
11300	DevelopedOpenLand-C	Pervious	C	1.85	2.23%
11400	DevelopedOpenLand-D	Pervious	D	--	--
12100	Forest-A	Pervious	A	--	--
12200	Forest-B	Pervious	B	--	--
12300	Forest-C	Pervious	C	--	--
12400	Forest-D	Pervious	D	--	--
13000	Water	N/A	N/A	--	--
			Total	**83.21**	**100%**

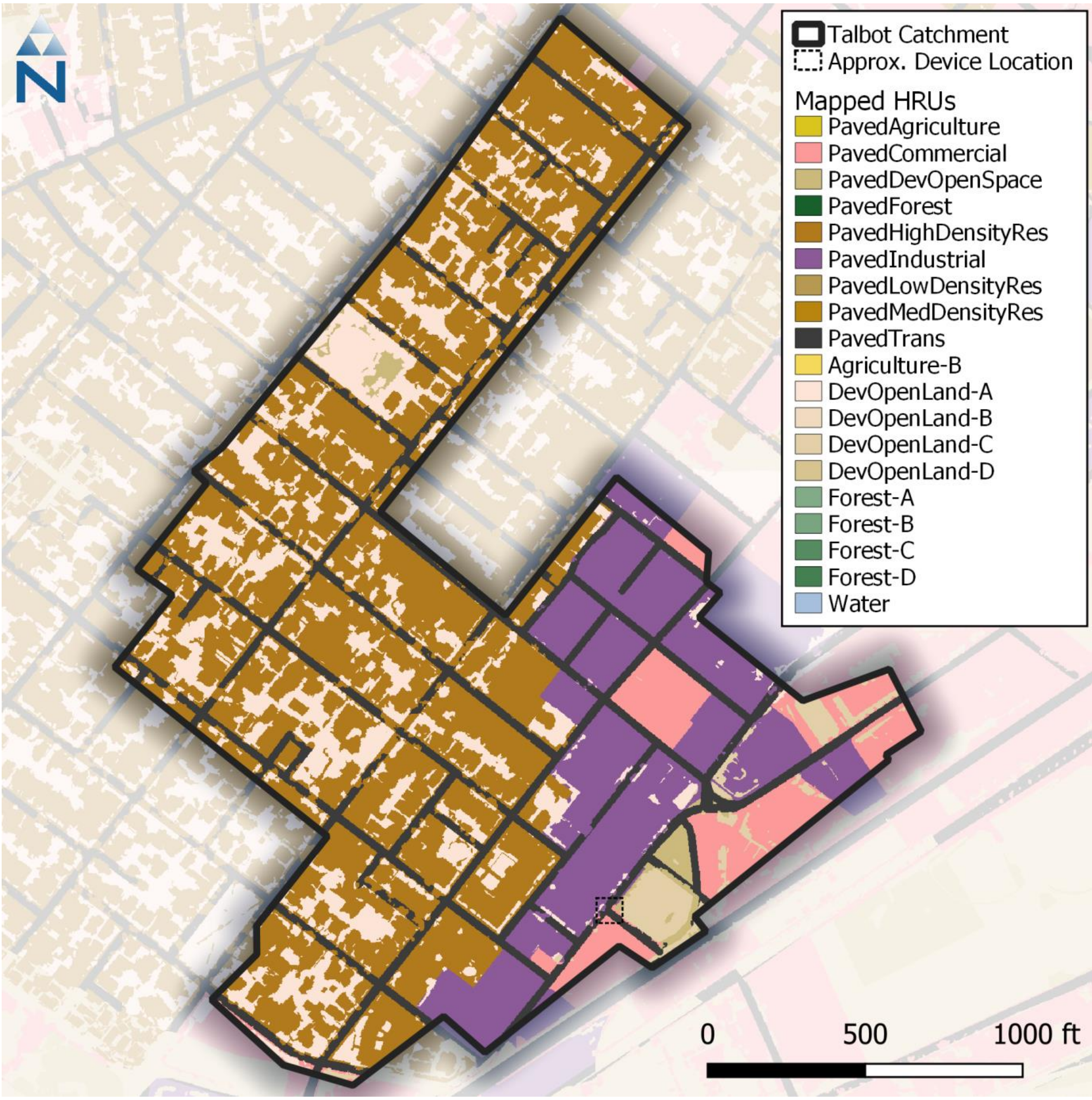

Figure 3-1. Mapped HRUs within the Talbot drainage area.

3.2 Opti-Tool HRU Time Series and Loading Rates

HRU time series of stormwater flow and pollutant loading are the primary inputs to SCMs simulated within the Opti-Tool. Two sets of HRU time series were used in the configuration/calibration of the Talbot device and the development of performance curves: i) those developed for the Cambridge area using local meteorological data and ii) long-term time series available as part of the Opti-Tool software package. Both sets of HRU time series include flow and pollutant loading for Total Phosphorus (TP), Total Nitrogen (TN), Total Suspended Solids (TSS), Zinc (Zn), and *E. coli* (most probable number [mpn]).

To configure and calibrate the Talbot deflection device, HRU time series were generated using the regionally calibrated Opti-Tool SWMM model and local meteorological data (i.e., hourly precipitation and daily minimum/maximum temperature) These pollutant loading rates were generated for the same period as the observed outfall data from the Talbot deflection device (Nov 2022 – Oct 2023). The development of these time series is documented in the Task 3A memo (Paradigm Environmental, 2024).

The long-term HRU time series from the Opti-Tool package were used for the development of generic deflection device performance curves, as discussed in Section 4. These time series were generated using the Opti-Tool's regionally calibrated SWMM model and meteorological data from the Boston Logan International Airport for a full 31-year period (Jan. 1992 – Dec. 2022). The Opti-Tool software package and details on its development and use are available from the EPA at https://www.epa.gov/tmdl/opti-tool-epa-region-1s-stormwater-management-optimization-tool. The mapping of Cambridge HRUs to Opti-Tool HRUs and their corresponding long-term annual average loading rates are shown in Table 3-2.

Table 3-2. HRU annual average loading rate for the Opti-Tool (Jan. 1992 – Dec. 2022)

Mapped HRU	Opti-Tool HRU	FLOW (MG/ac/year)	TP (lb/ac/year)	TN (lb/ac/year)	Zn (lb/ac/year)	TSS (lb/ac/year)	EColi (mpn/ac/year)
PavedAgriculture-IMP	Agriculture_I	1.09	1.50	11.44	0.71	646.58	1.14E+11
PavedCommercial-IMP	Commercial_I	1.09	1.80	15.25	1.37	376.05	9.59E+09
PavedDevelopedOpenSpace-IMP	OpenSpace_I	1.09	1.50	11.44	0.99	646.58	2.88E+12
PavedForest-IMP	Forest_I	1.09	1.50	11.44	0.71	646.58	2.88E+11
PavedHighDensityResidential-IMP	HighDensityRes_I	1.09	2.38	14.26	0.71	437.39	1.95E+12
PavedIndustrial-IMP	Commercial_I	1.09	1.80	15.25	1.37	376.05	9.59E+09
PavedLowDensityResidential-IMP	LowDensityRes_I	1.09	1.50	14.26	0.71	437.39	1.95E+12
PavedMediumDensityResidential-IMP	MedDensityRes_I	1.09	1.97	14.26	0.71	437.39	1.95E+12
PavedTransportation-IMP	Highway_I	1.09	1.39	10.26	1.76	1,474.83	2.28E+07
Agriculture-B	Agriculture_B	0.07	0.43	2.49	0.02	28.59	1.18E+10
DevelopedOpenLand-A	Pervious_A	0.01	0.03	0.26	0.01	6.81	7.76E+10
DevelopedOpenLand-B	Pervious_B	0.07	0.11	1.11	0.02	28.59	2.97E+11
DevelopedOpenLand-C	Pervious_C	0.15	0.21	2.33	0.05	58.85	6.35E+11
DevelopedOpenLand-D	Pervious_D	0.28	0.37	3.64	0.07	92.73	1.12E+12
Forest-A	Forest_A	0.01	0.03	0.12	0.01	6.81	7.76E+09
Forest-B	Forest_B	0.07	0.11	0.54	0.04	28.59	2.97E+10
Forest-C	Forest_C	0.15	0.21	1.16	0.09	58.85	6.35E+10
Forest-D	Forest_D	0.28	0.37	1.88	0.14	92.73	1.12E+11
Water	N/A	--	--	--	--	--	--

3.3 Deflection Device Configuration

As described in the Task 3A memo (Paradigm Environmental, 2024), the Talbot device was configured in the Opti-Tool as a generic deflection device. The Talbot device volume, orifice size, and weir properties were set based on the as-built specifications for the Talbot device as shown in Figure 3-2. The Talbot device Functional table (F-table) was developed based on the volume of the stormwater pipe network upstream of the Talbot device as estimated from the network's physical attributes (cross-sectional area and length) and the volume of the device itself. The F-table represents the depth-volume relationship upstream of the Talbot device as shown in Figure 3-3 and copied into the Opti-Tool worksheet "Card 714" as shown in Figure 3-4.

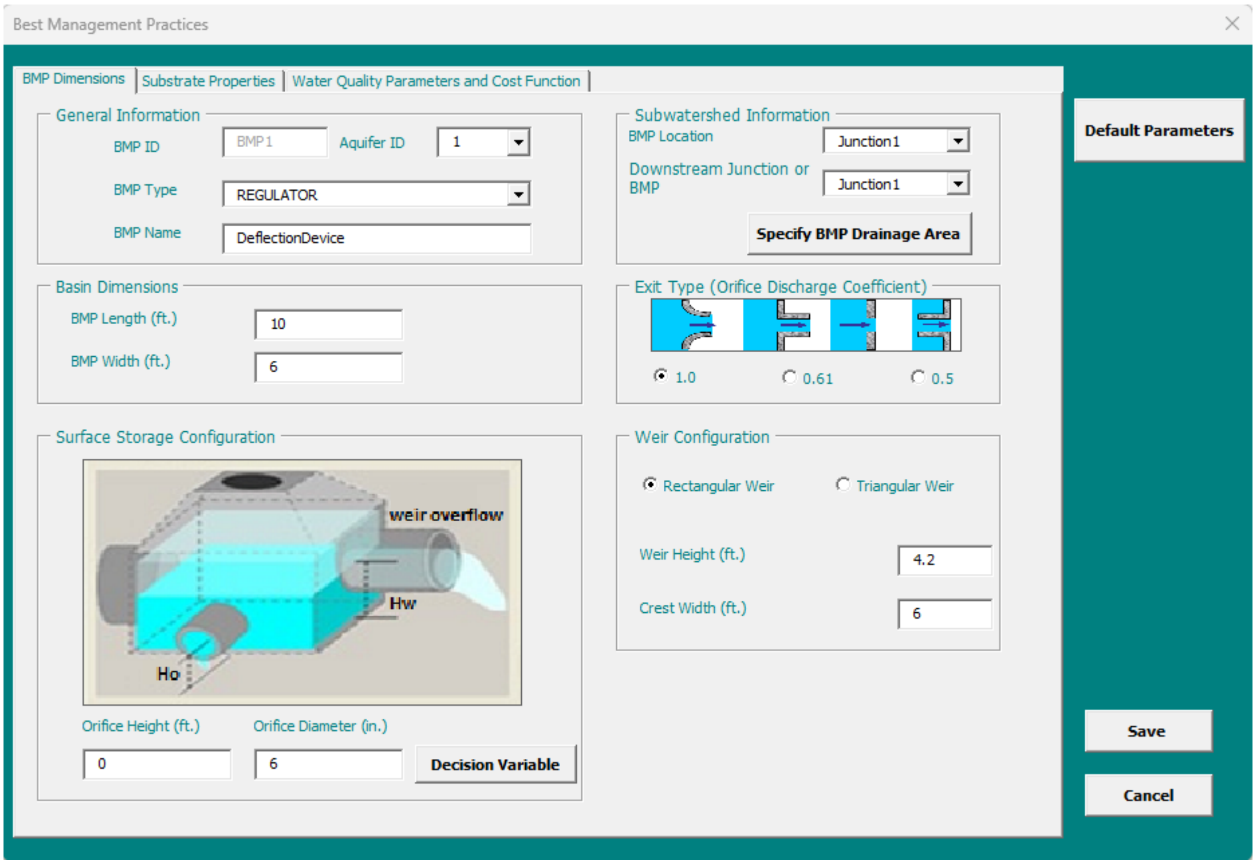

Figure 3-2. Opti-Tool Regulator schematic and details as configured for the Talbot device.

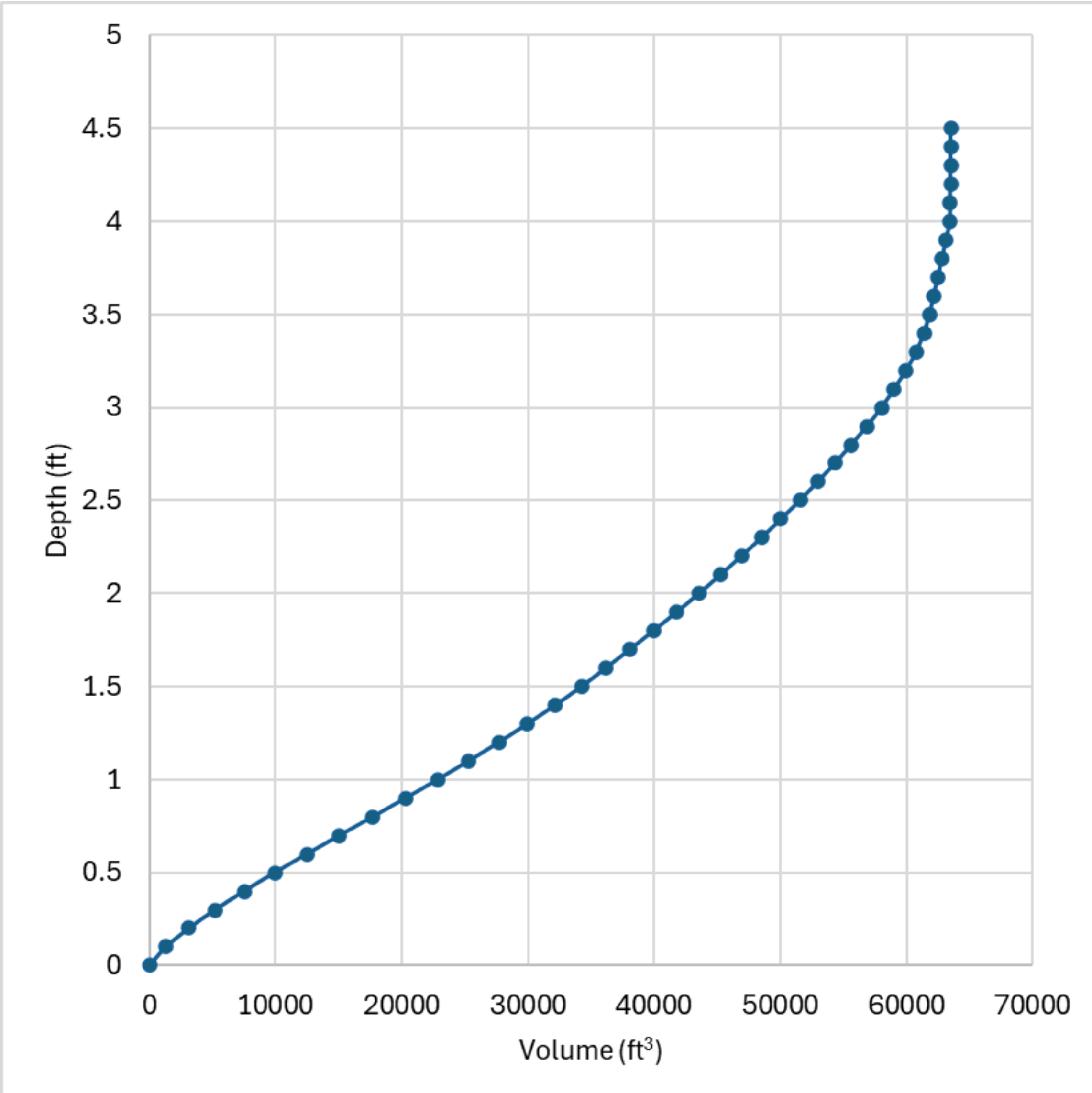

Figure 3-3. F-table for stormwater pipe network upstream of the Talbot deflection device.

Ftable for BMP Class A, B, and C

Create Input File

(Manually update this table as no interface was developed for this input)

FTABLE_ID	FLOW_LENGTH (ft)	BED_SLOPE	NUM_RECORD	BMPNAME (c715)
DEPTH (ft)	SURFACE_AREA (ac)	VOLUME (ac-ft)	FLOW_WEIR (cfs)	FLOW_ORIFICE (cfs)
FT1	13930	0.007263796	76	BMP1
0	0.001377405	0.000000	0	0
0.1	0.001377405	0.029890	0	0
0.2	0.001377405	0.071201	0	0
0.3	0.001377405	0.119109	0	0
0.4	0.001377405	0.171654	0	0
0.5	0.001377405	0.227548	0	0
0.6	0.001377405	0.285777	0	0
0.7	0.001377405	0.345414	0	0
0.8	0.001377405	0.405649	0	0
0.9	0.001377405	0.465543	0	0
1	0.001377405	0.524121	0	0
1.1	0.001377405	0.580340	0	0
1.2	0.001377405	0.635380	0	0
1.3	0.001377405	0.687763	0	0
1.4	0.001377405	0.738202	0	0
1.5	0.001377405	0.786068	0	0
1.6	0.001377405	0.830421	0	0
1.7	0.001377405	0.874243	0	0
1.8	0.001377405	0.917159	0	0
1.9	0.001377405	0.959232	0	0
2	0.001377405	0.999945	0	0
2.1	0.001377405	1.038902	0	0
2.2	0.001377405	1.076946	0	0
2.3	0.001377405	1.113657	0	0
2.4	0.001377405	1.149320	0	0
2.5	0.001377405	1.183527	0	0
2.6	0.001377405	1.215951	0	0
2.7	0.001377405	1.247332	0	0
2.8	0.001377405	1.277453	0	0
2.9	0.001377405	1.305996	0	0
3	0.001377405	1.332243	0	0
3.1	0.001377405	1.355670	0	0
3.2	0.001377405	1.377211	0	0
3.3	0.001377405	1.395728	0	0
3.4	0.001377405	1.409785	0	0
3.5	0.001377405	1.419816	0	0
3.6	0.001377405	1.427620	0	0
3.7	0.001377405	1.435166	0	0
3.8	0.001377405	1.442568	0	0
3.9	0.001377405	1.449946	0	0
4	0.001377405	1.457298	0	0
4.1	0.001377405	1.457637	0	0
4.2	0.001377405	1.457940	0	0
4.3	0.001377405	1.458201	0	0
4.4	0.001377405	1.458407	0	0
4.5	0.001377405	1.458526	0	0
4.6	0.001377405	1.458538	0	0

Figure 3-4. Talbot device F-table within the Opti-Tool on Card 714.

3.4 Device Calibration and Validation

The Talbot defection device performance was evaluated by quantifying the flow and load deflected to the sanitary system through the orifice. The total inflow is the sum of runoff volume from all HRUs within the device drainage area. Flow through the orifice is assumed to be treated and the remaining flow represents the untreated stormwater draining to the river. The Talbot device was calibrated by adjusting the percentage of directly connected impervious area (DCIA) to match the estimated deflection value of 90% for the 1992 typical year calculated by the City of Cambridge and Stantec using the simple method (City of Cambridge and Stantec, 2023). The Massachusetts Water Resources Authority (MWRA) uses a modified 1992 rainfall time series as a "Typical Year" representing the 40-year (1949-1987) average in total rainfall and distribution of rainfall events of different sizes. After the DCIA adjustment, 90% of the flow into the Talbot device was diverted for the Nov 2022 – Oct 2023 time period. This equates to a 95% reduction in TP load and a 94% reduction in TN load.

After calibration of DCIA was performed, the Talbot device was validated using the Opti-Tool HRU time series from the Boston Logan International Airport for both 1992 and the full Opti-Tool time period (1992 – 2022). In terms of diverted flow volume, the performance over the calibration period (Nov 2022 – Oct 2023) was within 1 percentage point of the 1992 year using the observed Boston Logan climate time series (Table 3-3); the simulated pollutants had similar differences in percentage diverted as the flow. Over the long-term simulation, annual average flow and pollutant diversion increased slightly compared to the single-year simulations, with 92% diverted flow and 96% and 95% diverted TP and TN, respectively. Full details of the Talbot device calibration and validation are documented in the Task 3A memo (Paradigm Environmental, 2024).

Table 3-3. Calibration and validation results for the Talbot deflection device

Simulation Period	Percentage Diverted Flow and Pollutants					
	Flow Volume	TP Load	TN Load	ZN Load	TSS Load	E. coli Load
Nov 2022 – Oct 2023[1]	90.0%	94.8%	94.0%	78.5%	78.4%	94.3%
Jan 1992 – Dec 1992[2]	89.0%	95.9%	94.5%	78.1%	77.8%	92.4%
Jan 1992 – Dec 2022[2]	92.0%	96.0%	95.3%	83.4%	83.2%	95.1%

[1] USGS Fresh Pond meteorological data
[2] Opti-Tool Boston Logan International Airport meteorological data

4 CUMULATIVE PERFORMANCE CURVES

An Opti-Tool performance curve shows the percent reduction in flow or pollutant load from an SCM for a range of storage capacities (defined as runoff depth captured from the SCM's IC drainage area). Because these curves are based on long-term continuous simulation, they represent cumulative reductions over a wide range of storm and antecedent moisture conditions. As such, these curves provide a more realistic picture of long-term SCM performance for planning and crediting purposes, as opposed to performance for a single storm event or synthetic design storm.

To create generic performance curves for a Sewer Deflection device, the long-term flow and the modeled pollutant loads (i.e., TP, TN, Zn, TSS, and E.coli) diverted from the calibrated Talbot deflection device were simulated using the Opti-Tool HRU time series for 31 years (as discussed in Section 3.2). A single set of performance curves (1 flow curve and 5 pollutant curves) represents a specific deflection device configuration based on a set orifice diameter and weir height over 20 scenarios varying the captured runoff depth from 0.1 inches to 2.0 inches with an increment of 0.1 inches. The captured runoff depth represents the physical storage capacity of the device and the connected stormwater pipe network and is based on a scaled version of the Talbot device system.

A total of 45 sets of performance curves were developed and are presented in the following subsections. The first set of performance curves represents a device as configured and calibrated to specifically represent the Talbot deflection device (Section 4.1). Fifteen sets of performance curves were developed with varying pipe slope and orifice diameter to represent scenarios with inline pipe diversion or no weir as described in Sections 4.2 through 4.4. Twenty-nine sets of performance curves were developed with varying orifice diameter and weir height configurations for the Talbot device as described in Sections 4.5 through 4.9.

4.1 Talbot Device Configuration (Weir Height and Orifice Size)

Figure 4-1 provides a set of performance curves developed for the calibrated Talbot deflection device configured with the as-built orifice diameter (6-in) and weir height (4.2-ft). The configured device's capture runoff depth was varied between 0.1-in and 2-in; the as-built capture depth, based on the upstream stormwater pipe network and device storage capacity was estimated as 0.3-in. With this configuration, nearly all flow and load are diverted with a runoff capture depth of 1-in.

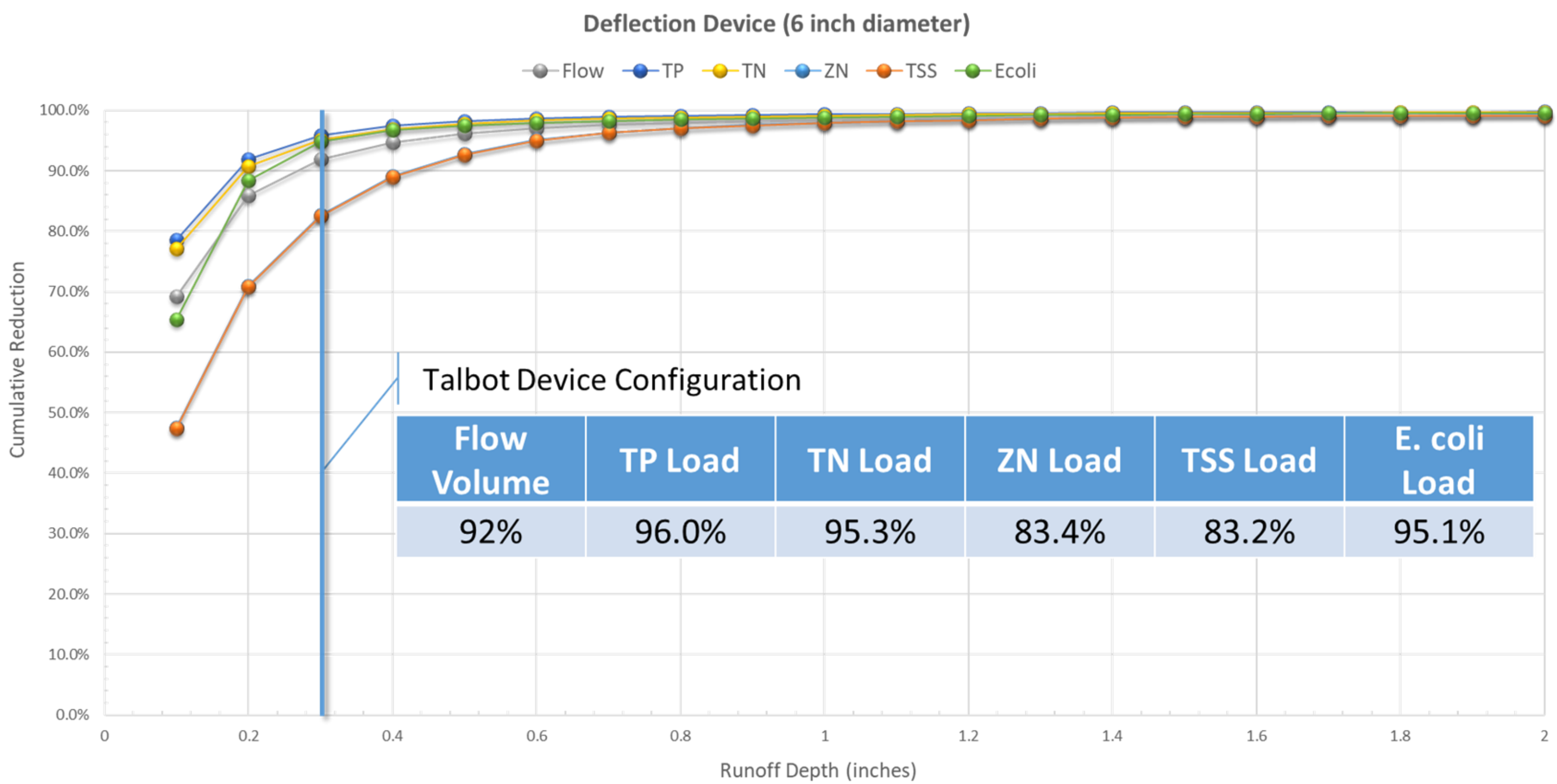

Figure 4-1. Talbot device (orifice diameter = 6 in, weir height = 4.2 ft) performance curve.

4.2 No Weir with Varying Orifice Diameter and 0.189% Pipe Slope

To represent deflection scenarios where there is no device creating temporary storage volume (e.g., flow partially diverted via an orifice in a pipe wall), 5 sets of performance curves were developed assuming the orifice is located near the bottom of the side of the inflow storm drain pipe, with no weir configuration. For these scenarios, pipe slope is an important factor controlling the amount of water that can be diverted and can be calculated from the length and elevation difference between the upstream and downstream invert elevations of the pipe with the deflection device. This configuration is similar to that of the City of Cambridge's Endicott device, as shown in Figure 4-2.

The pipe flow rate for the no-weir configuration was calculated using Manning's equation, which accounts for the pipe size, bed slope, and roughness coefficient. A pipe bed slope of 0.189% was calculated based on the dimensions of the Talbot device inflow pipe. A roughness coefficient of 0.015 and a pipe size of 4.5 ft were used for all calculations when no weir was configured. The relationship between the flow depth and flow rate in the pipe was denoted as FLOW_WEIR in the F-table. Additionally, the orifice diversion flow rate was estimated using the orifice equation and represented as FLOW_ORIFICE in the F-table. Opti-Tool utilized the F-table to simulate the water through the pipe and orifice based on the water depth at any given 5-minute simulation interval.

Orifice size was then varied between 6-in, 9-in, 12-in, 15-in, and 18-in as shown in Figure 4-3 to Figure 4-7, respectively, to evaluate changes in performance. These curves indicate that without a structure to provide temporary storage, the flow rate through the orifice limits the amount of flow that can be diverted; when the orifice flow rate (a function of the head) is exceeded, the remaining flow cannot be diverted. As the orifice size increases, more flow can be diverted. At 0.3 inches of runoff capture, the percentage of diverted flow ranges from approximately 26% for the 6-inch orifice to approximately 59% for the 18-inch orifice.

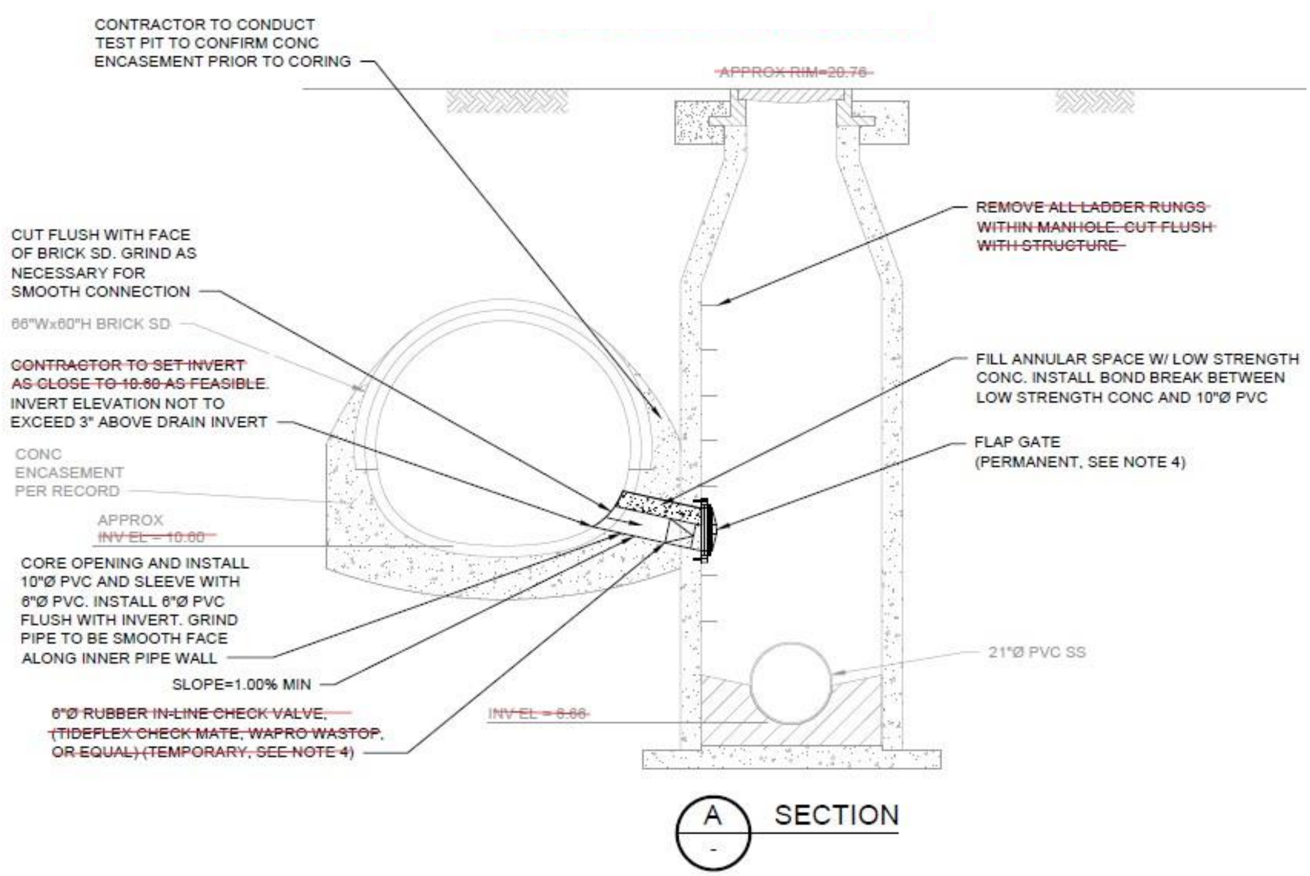

Figure 4-2. As-built specifications for the Endicott device illustrating the conduit diverting stormwater flow (left) into the sanitary sewer (right) (from Kleinfelder and Stantec, 2020).

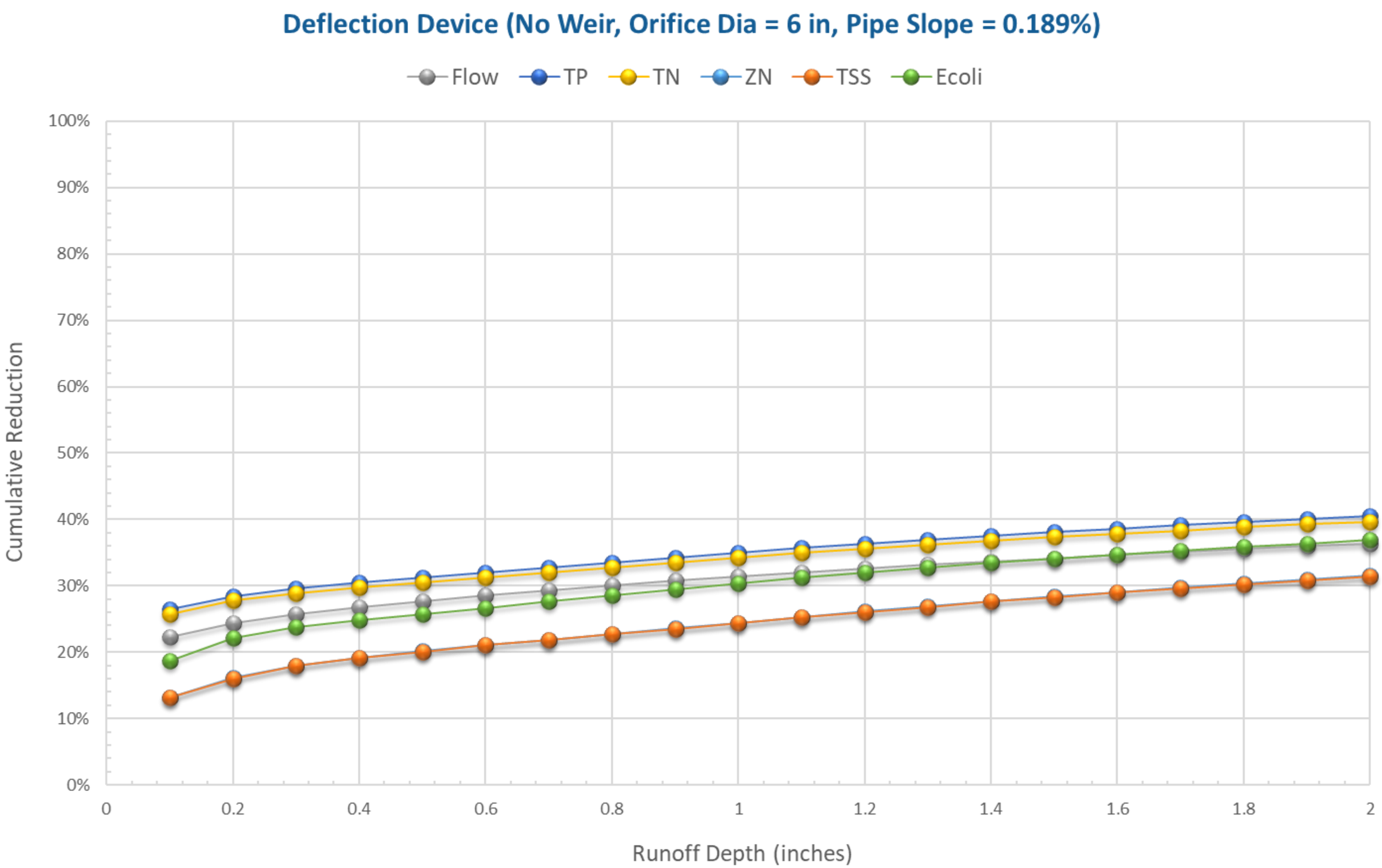

Figure 4-3. Deflection device (no weir, orifice diameter = 6 in, pipe slope = 0.189%) performance curve.

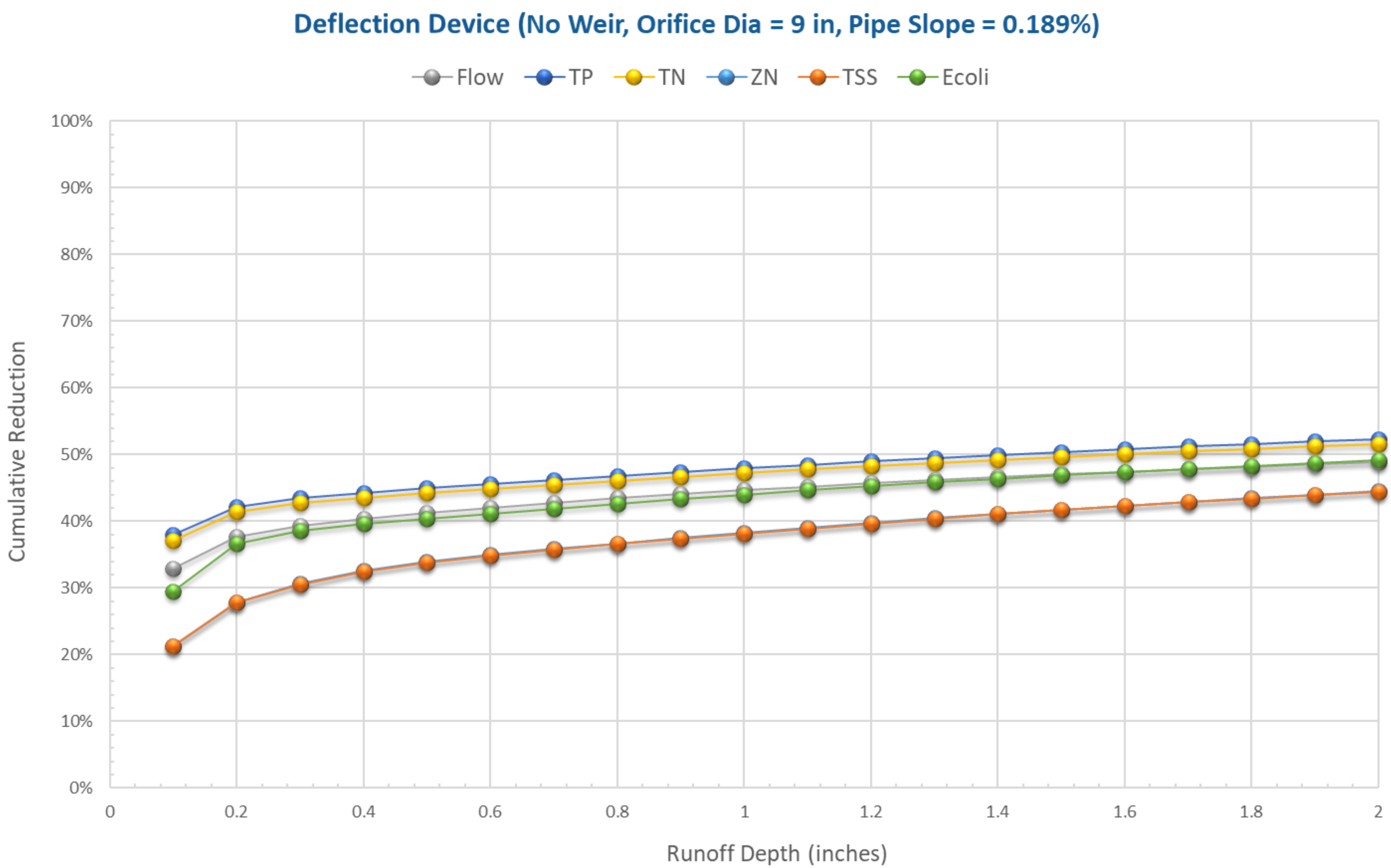

Figure 4-4. Deflection device (no weir, orifice diameter = 9 in, pipe slope = 0.189%) performance curve.

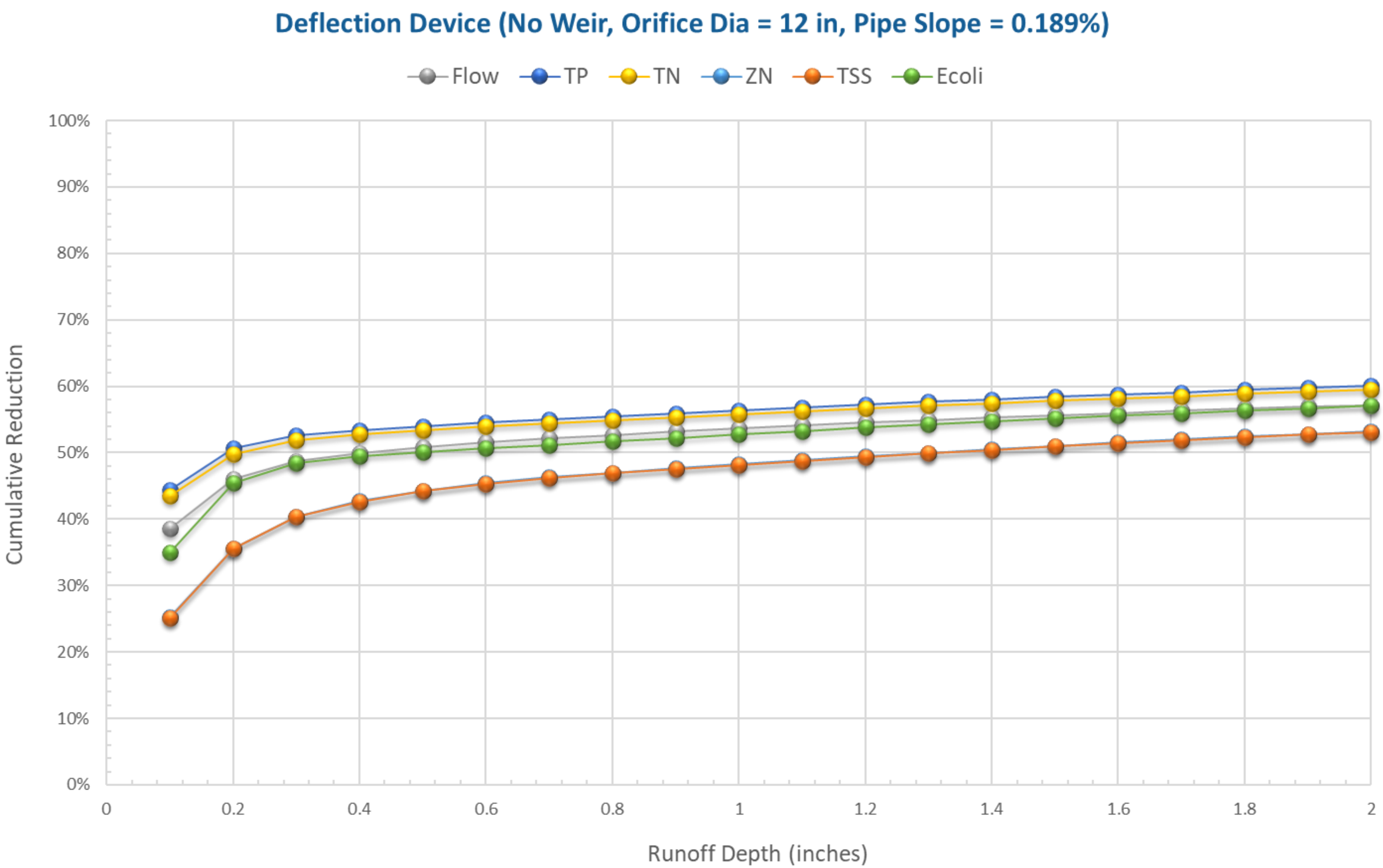

Figure 4-5. Deflection device (no weir, orifice diameter = 12 in, pipe slope = 0.189%) performance curve.

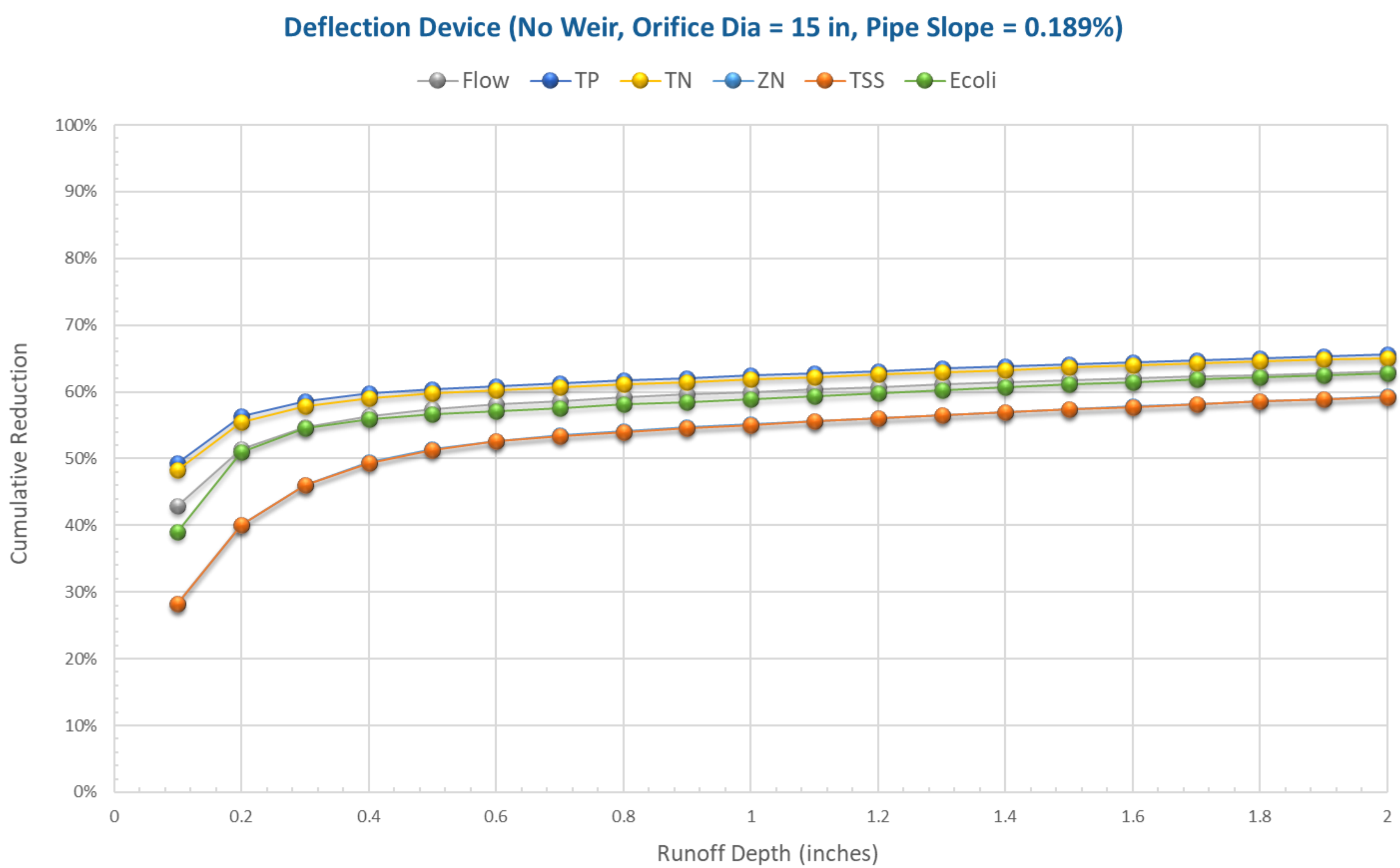

Figure 4-6. Deflection device (no weir, orifice diameter = 15 in, pipe slope = 0.189%) performance curve.

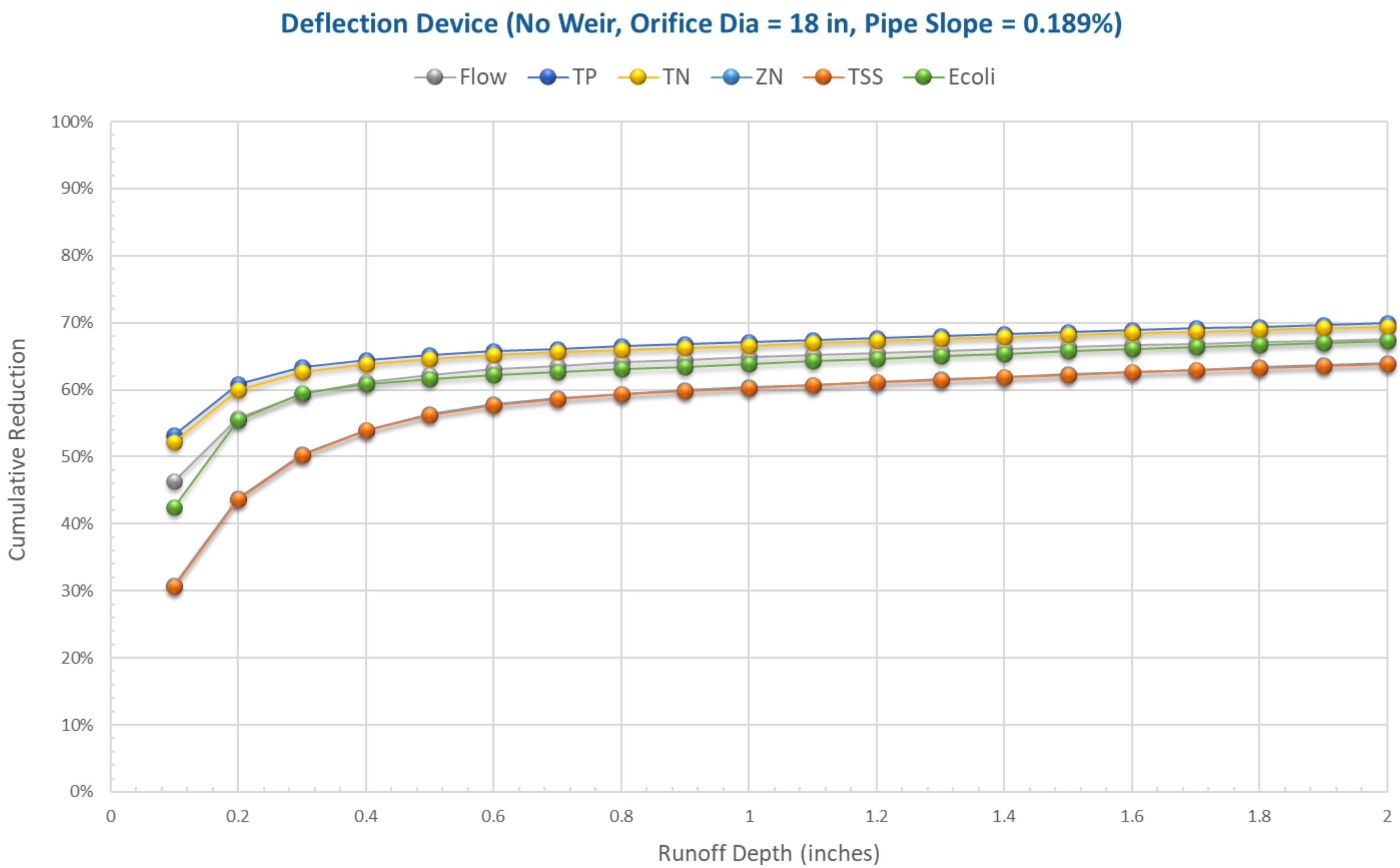

Figure 4-7. Deflection device (no weir, orifice diameter = 18 in, pipe slope = 0.189%) performance curve.

4.3 No Weir with Varying Orifice Diameter and 0.5% Pipe Slope

Five additional sets of performance curves were developed with pipe slope changed to 0.5% for the no weir device configuration assuming the orifice is located in one of the inflow storm drain pipes of 4.5 ft diameter.

The performance curves in Figure 4-8 to Figure 4-12 illustrate the impact of varying orifice sizes with a fixed pipe diameter and bed slope. Orifice diameter was varied in 3-inch increments between 6 inches and 18 inches. These curves exhibit a similar trend as seen in a 0.189% pipe slope but with relatively lower performance due to increased velocity resulting in increased pipe flow rate.

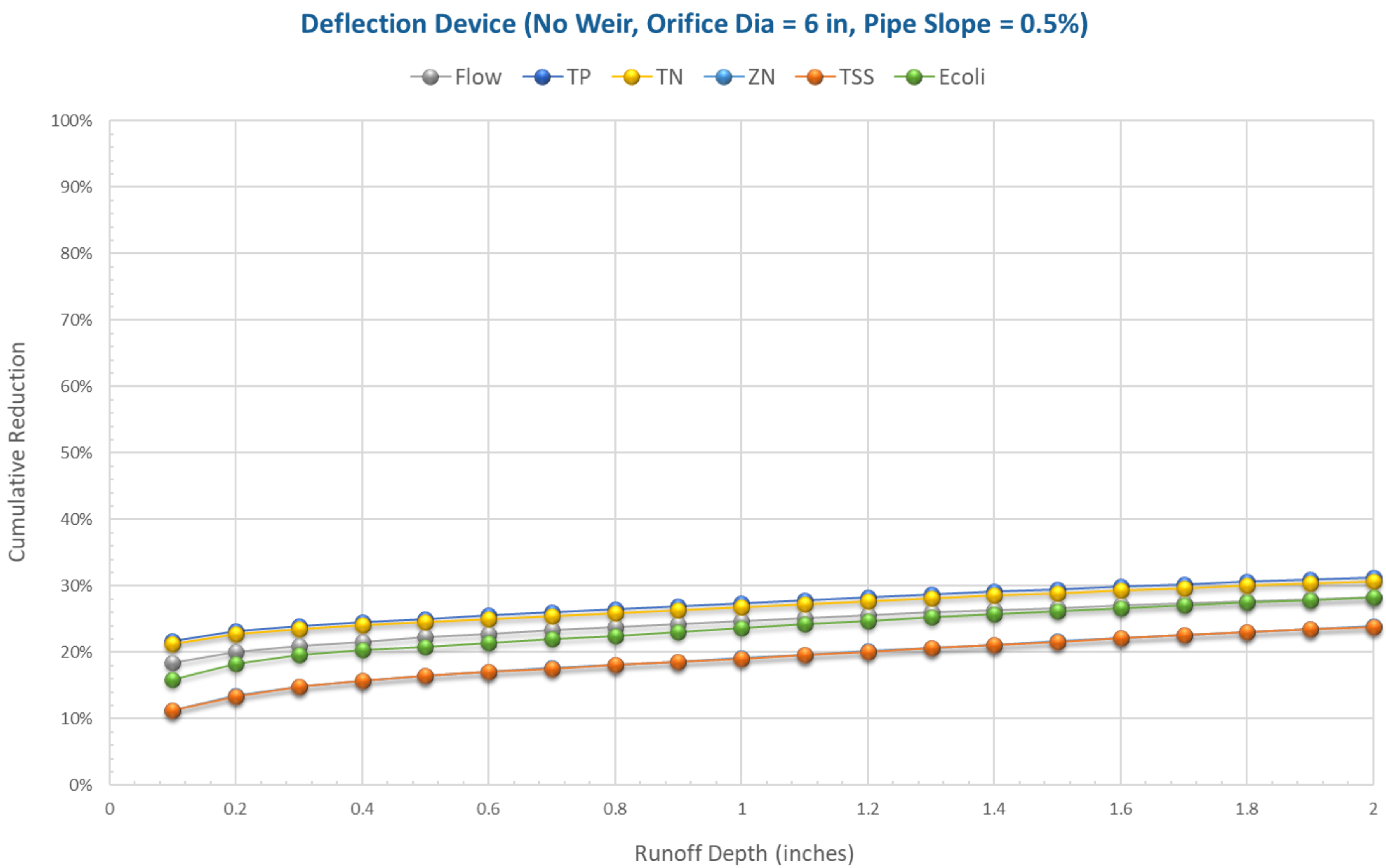

Figure 4-8. Deflection device (no weir, orifice diameter = 6 in, pipe slope = 0.5%) performance curve.

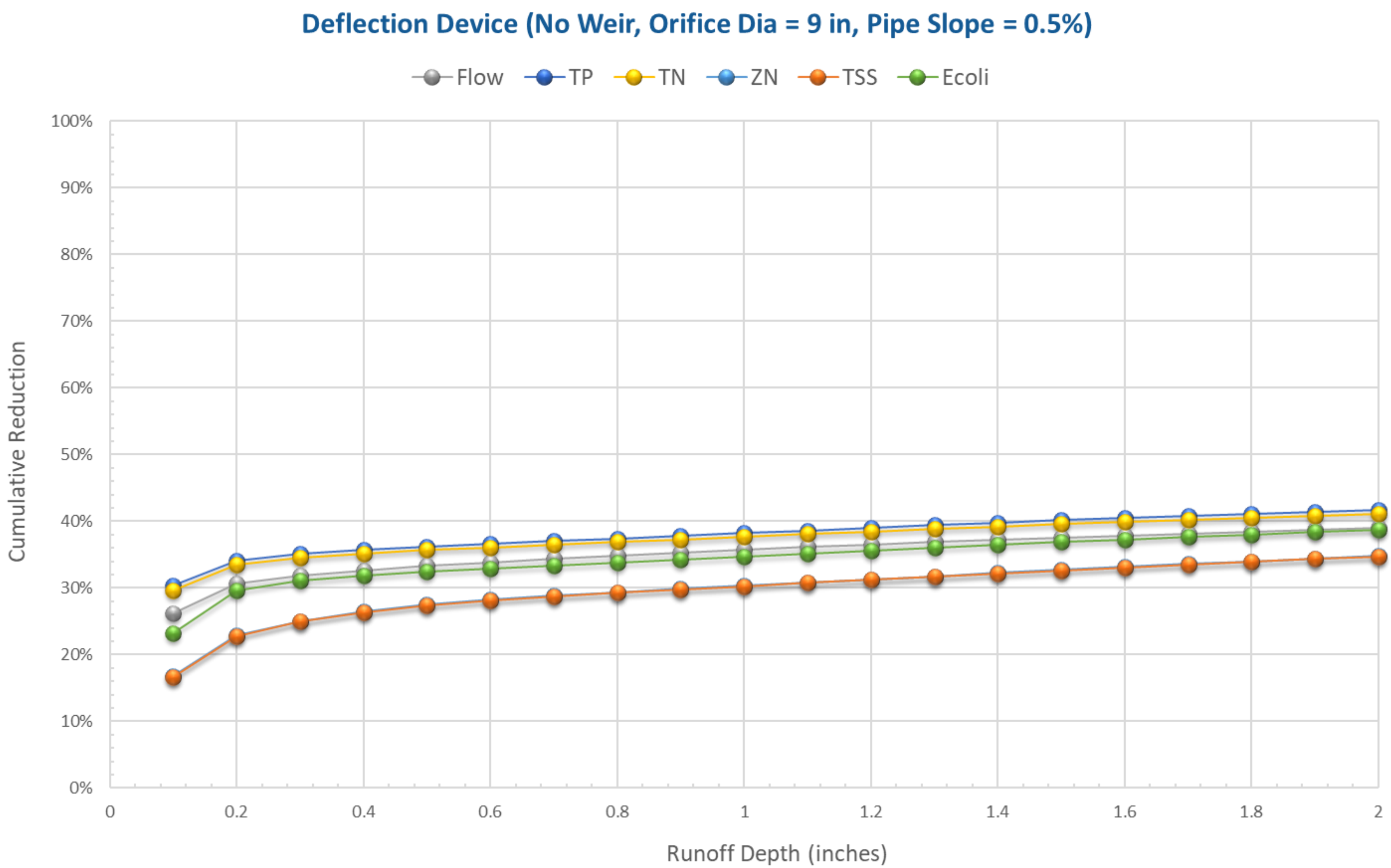

Figure 4-9. Deflection device (no weir, orifice diameter = 9 in, pipe slope = 0.5%) performance curve.

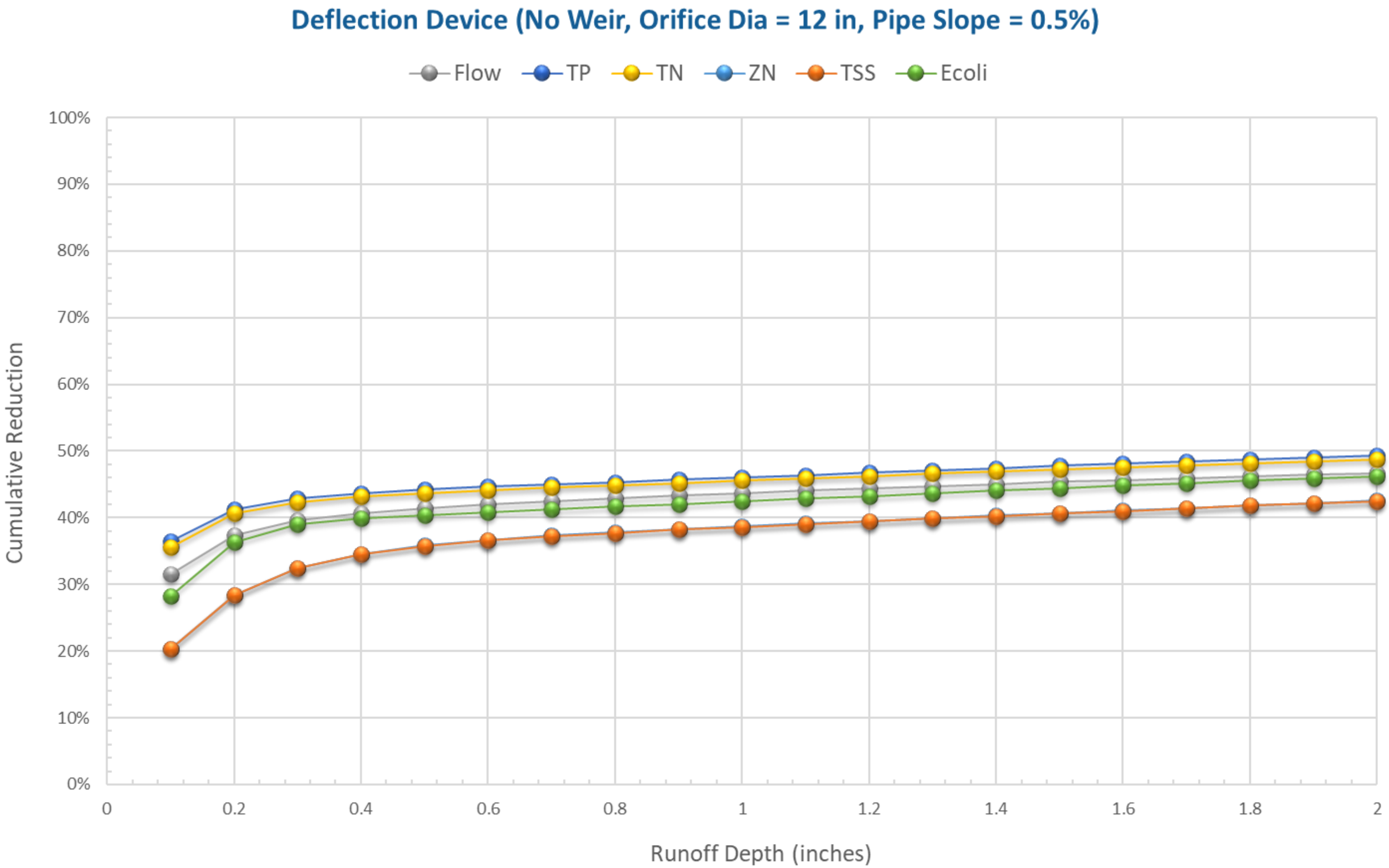

Figure 4-10. Deflection device (no weir, orifice diameter = 12 in, pipe slope = 0.5%) performance curve.

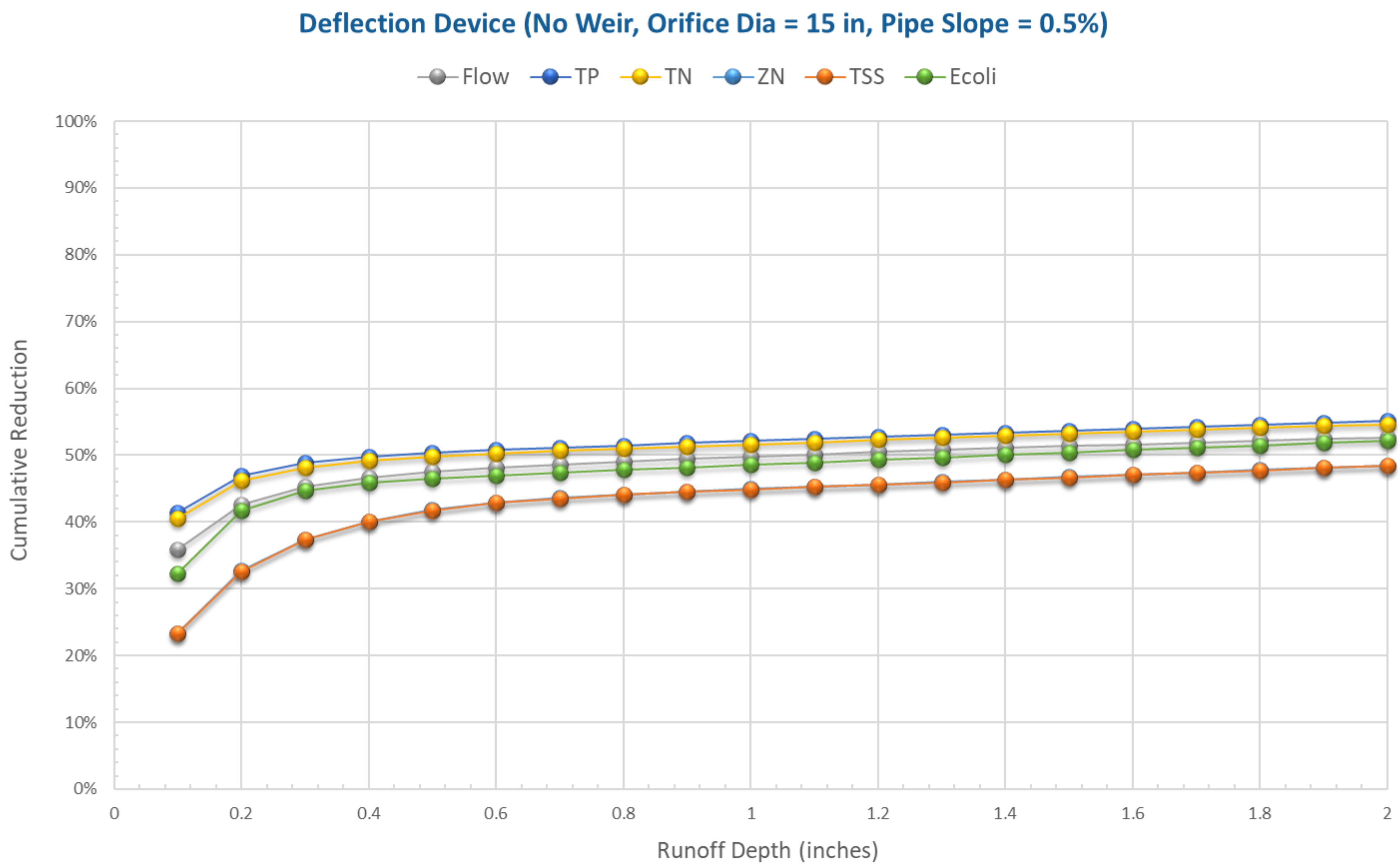

Figure 4-11. Deflection device (no weir, orifice diameter = 15 in, pipe slope = 0.5%) performance curve.

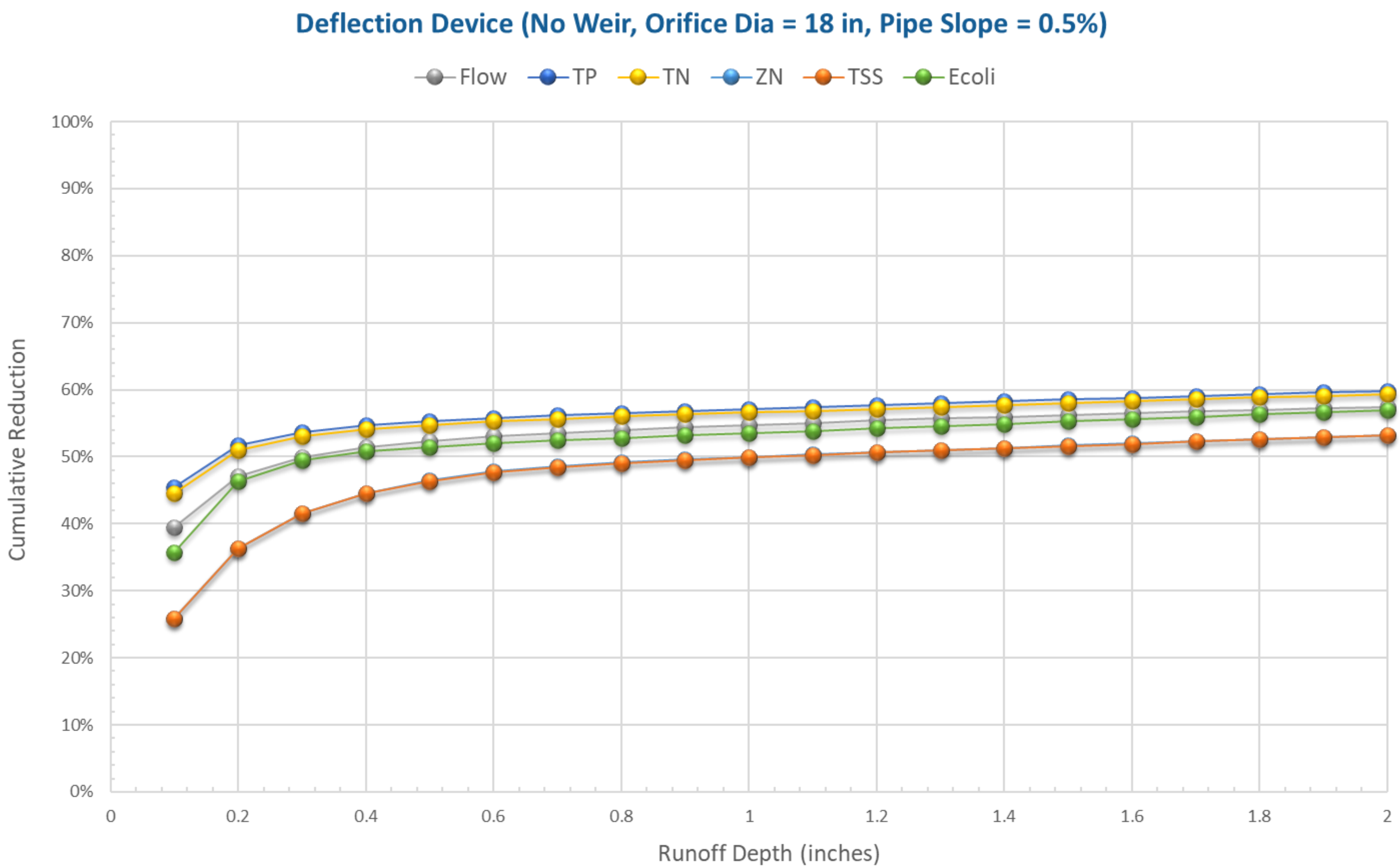

Figure 4-12. Deflection device (no weir, orifice diameter = 18 in, pipe slope = 0.5%) performance curve.

4.4 No Weir with Varying Orifice Diameter and 0.04% Pipe Slope

Five additional sets of performance curves were developed with pipe slope changed to 0.04% for the no weir configuration assuming the orifice is located in one of the inflow storm drain pipes of 4.5 ft diameter.

The performance curves in Figure 4-13 to Figure 4-17 illustrate the impact of varying orifice sizes with a fixed pipe diameter and bed slope. Orifice diameter was varied in 3-inch increments between 6 inches and 18 inches. These curves exhibit a similar trend as seen in a 0.189% pipe slope but with relatively higher performance due to reduced velocity resulting in reduced pipe flow rate.

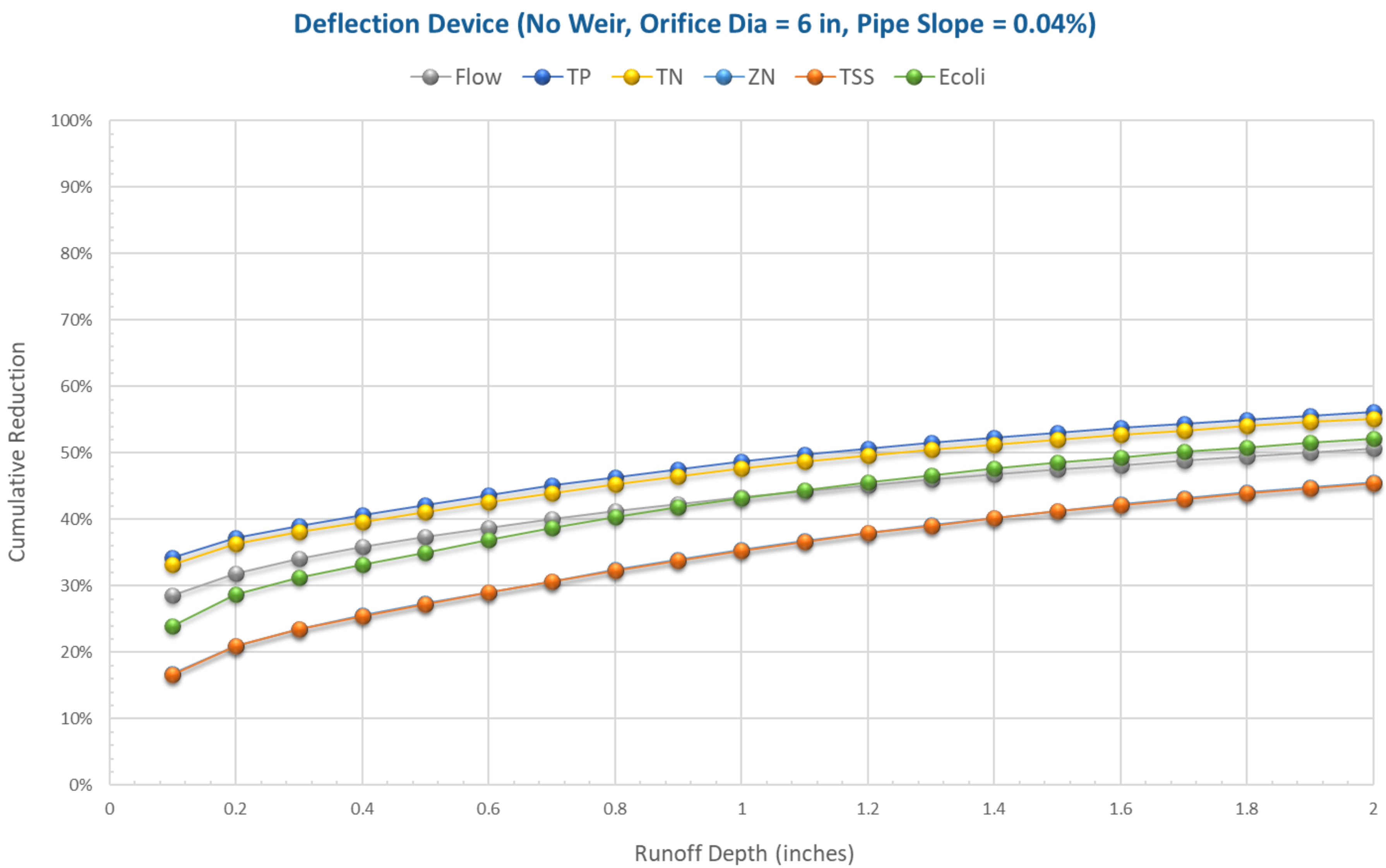

Figure 4-13. Deflection device (no weir, orifice diameter = 6 in, pipe slope = 0.04%) performance curve.

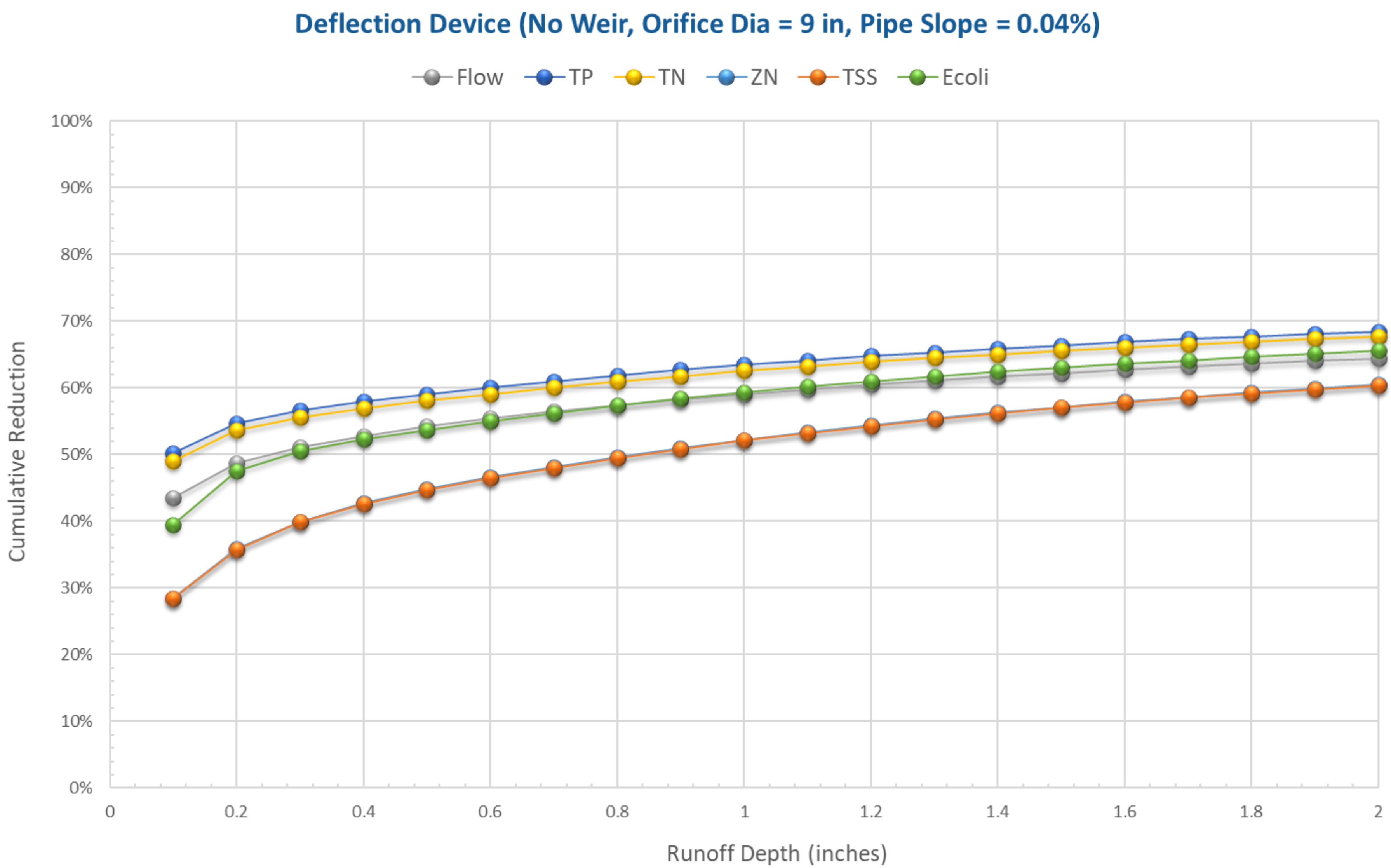

Figure 4-14. Deflection device (no weir, orifice diameter = 9 in, pipe slope = 0.04%) performance curve.

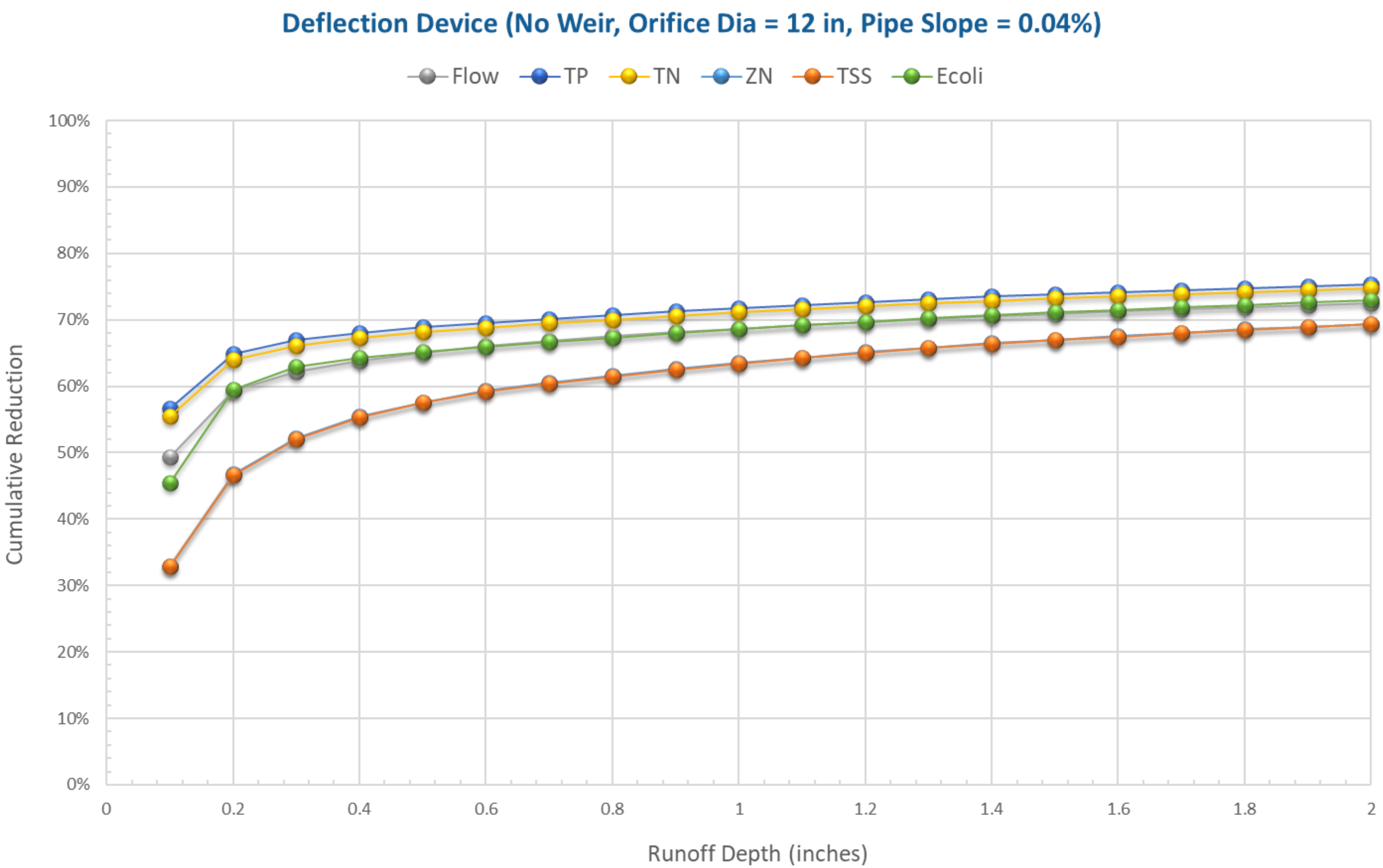

Figure 4-15. Deflection device (no weir, orifice diameter = 12 in, pipe slope = 0.04%) performance curve.

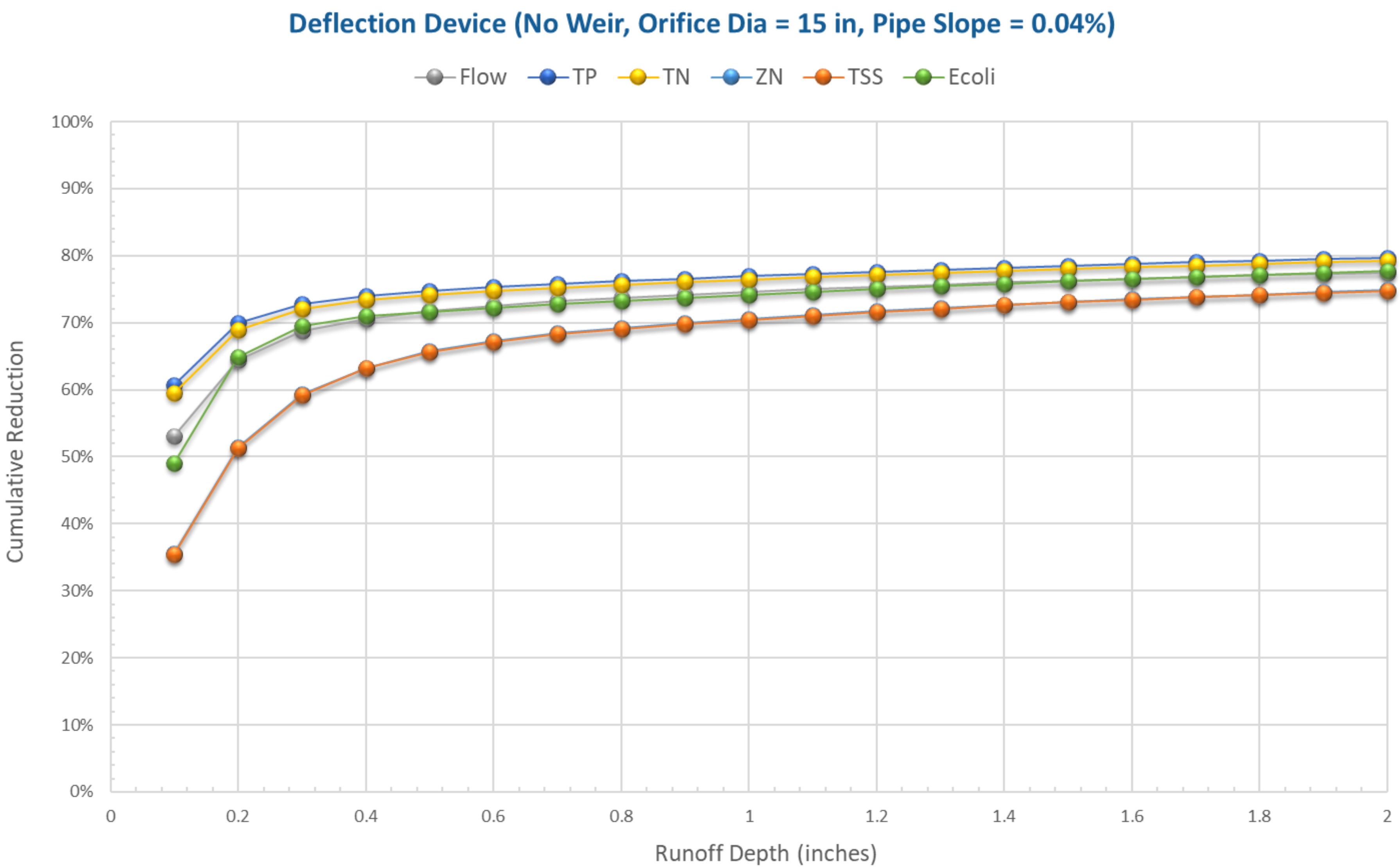

Figure 4-16. Deflection device (no weir, orifice diameter = 15 in, pipe slope = 0.04%) performance curve.

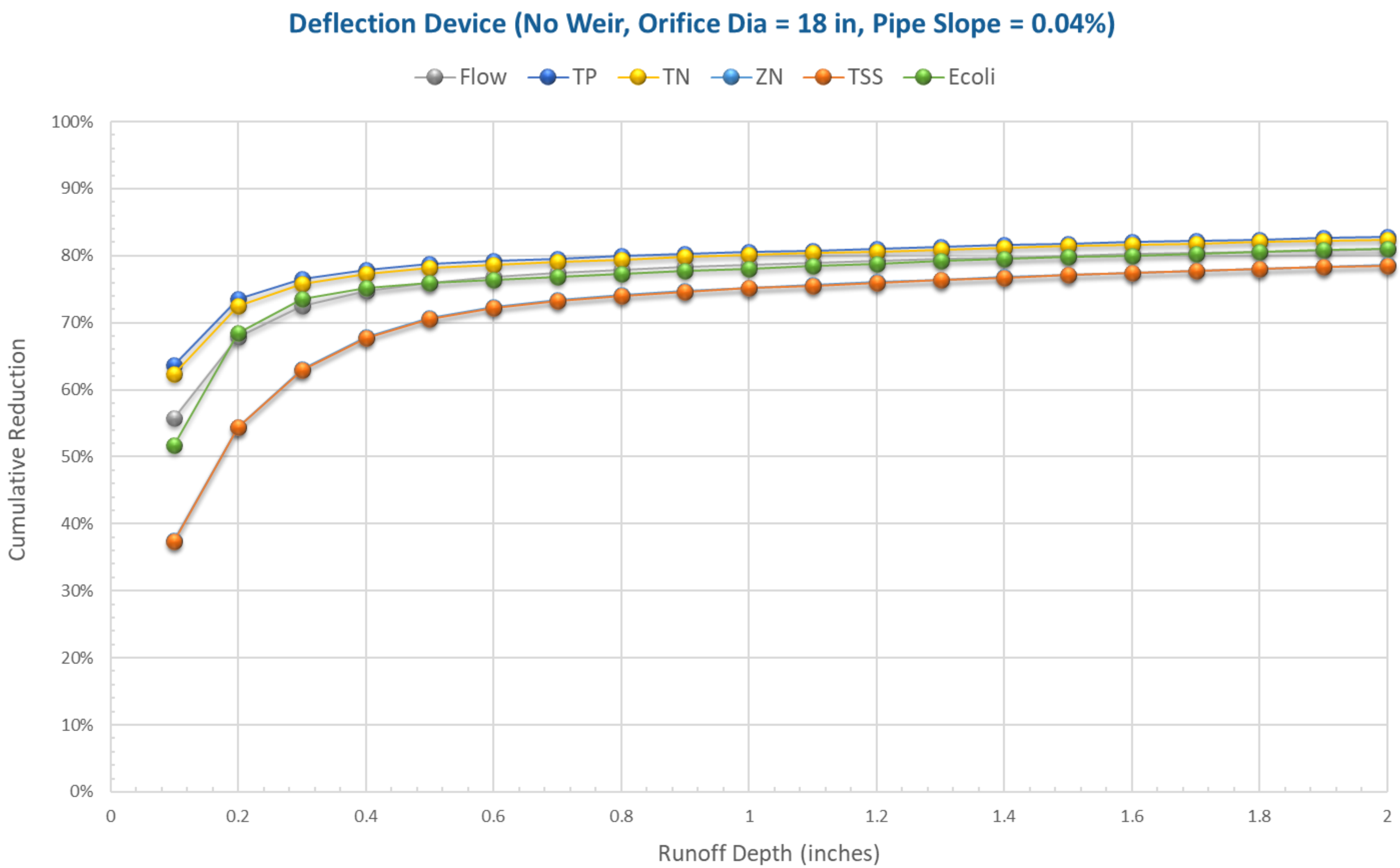

Figure 4-17. Deflection device (no weir, orifice diameter = 18 in, pipe slope = 0.04%) performance curve.

4.5 6-inch Orifice Diameter with Varying Weir Height

The performance curves in Figure 4-18 to Figure 4-25 illustrate the impact of varying weir height (i.e., the amount of temporary storage) with a fixed orifice size (6-in). Weir height was varied with a 0.5-ft increment between 0.5-ft and 4-ft. With a weir height of 0.5-ft, the relationship between percentage reduction and runoff capture depth was roughly linear; as weir height increased, higher percentage reductions were achieved, and the curves flattened out at higher runoff capture depths.

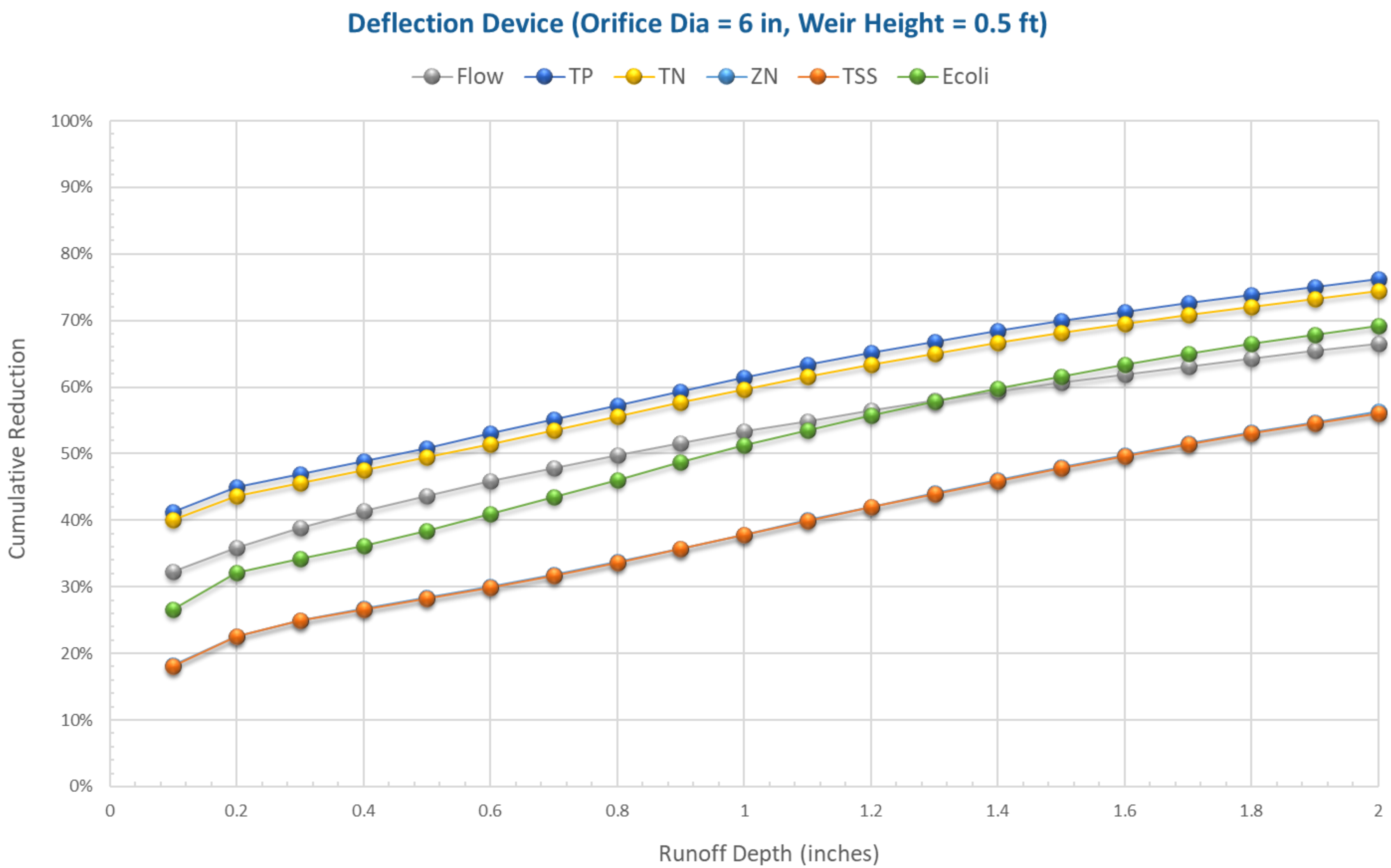

Figure 4-18. Deflection device (orifice diameter = 6 in, weir height = 0.5 ft) performance curve.

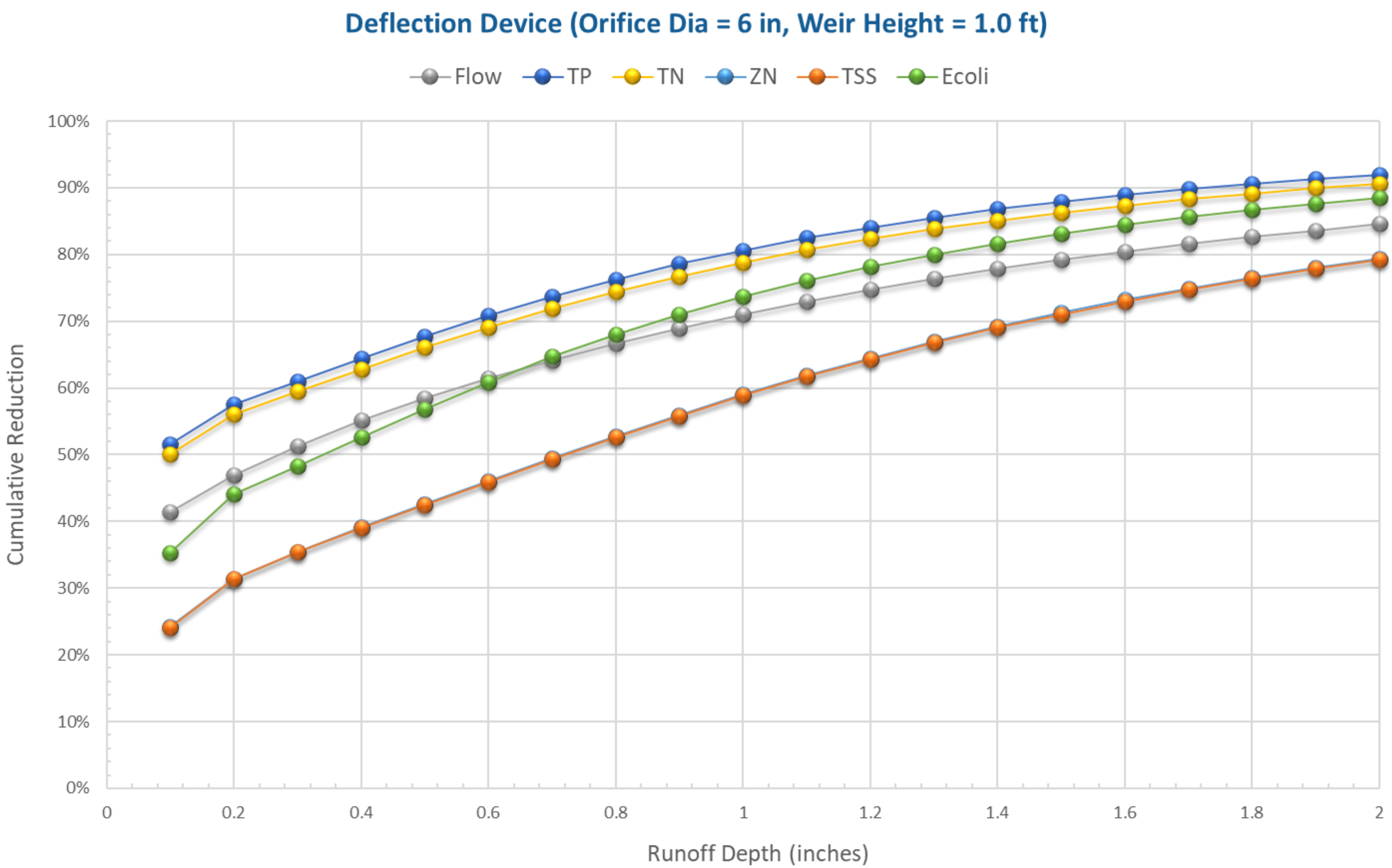

Figure 4-19. Deflection device (orifice diameter = 6 in, weir height = 1.0 ft) performance curve.

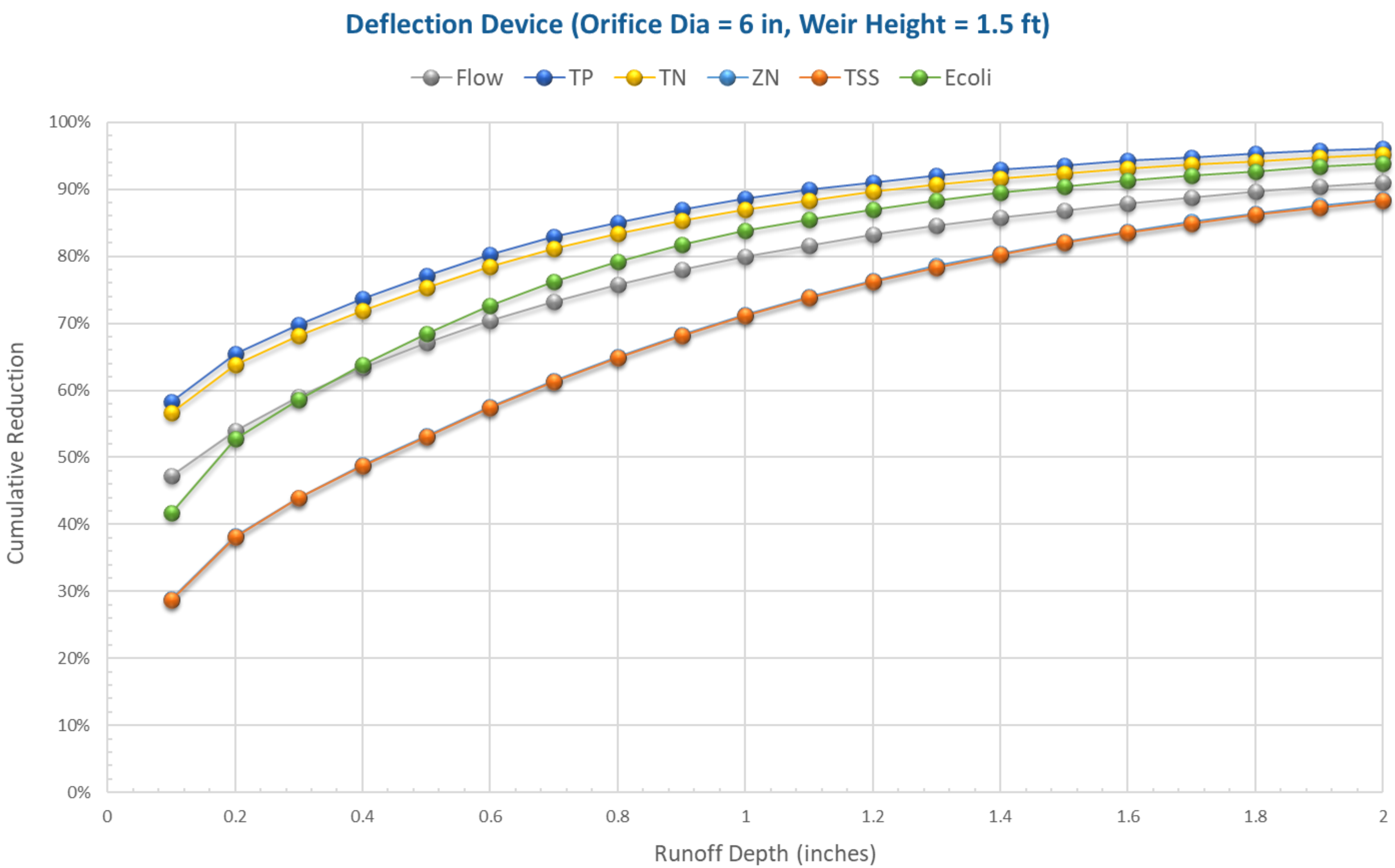

Figure 4-20. Deflection device (orifice diameter = 6 in, weir height = 1.5 ft) performance curve.

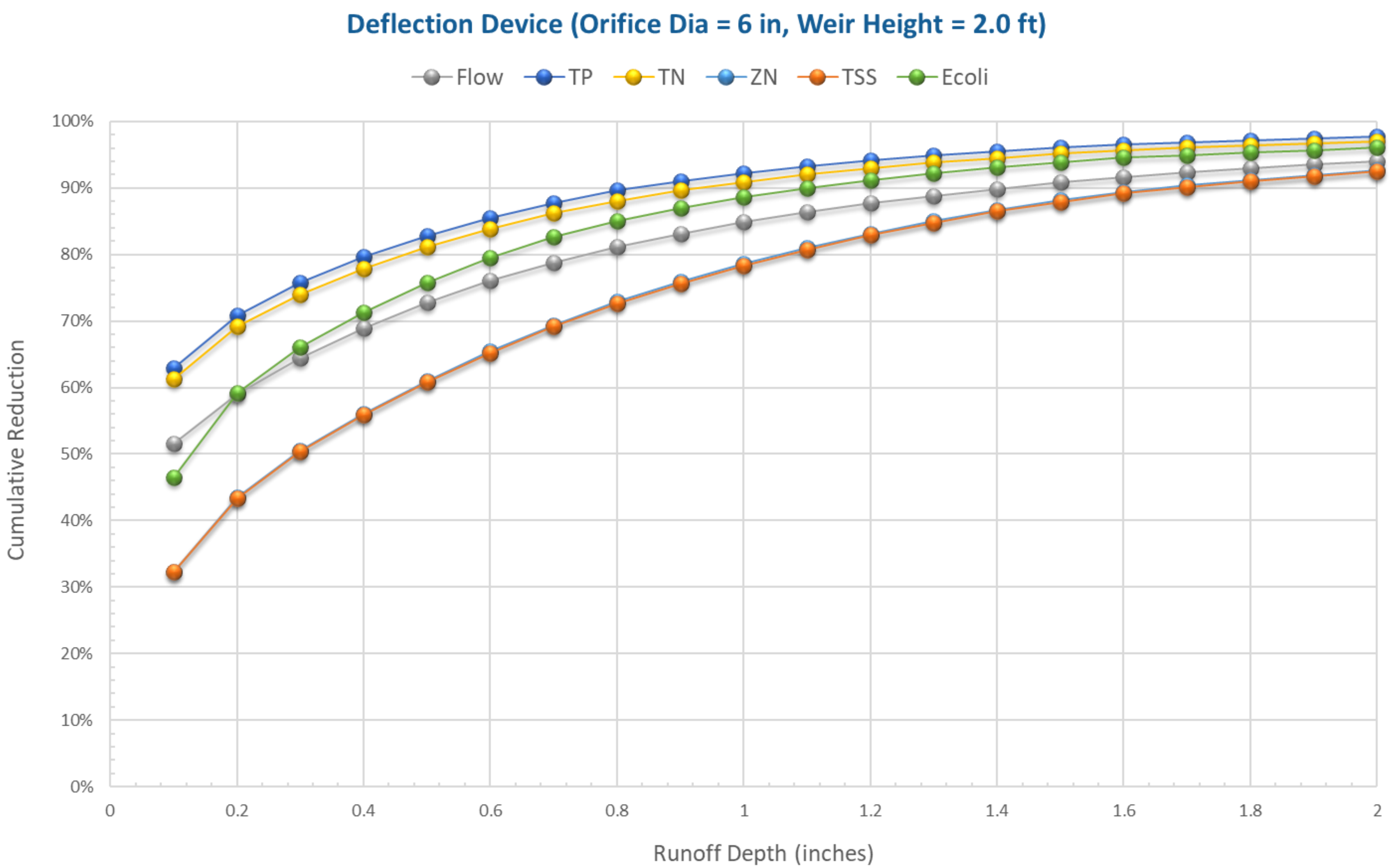

Figure 4-21. Deflection device (orifice diameter = 6 in, weir height = 2.0 ft) performance curve.

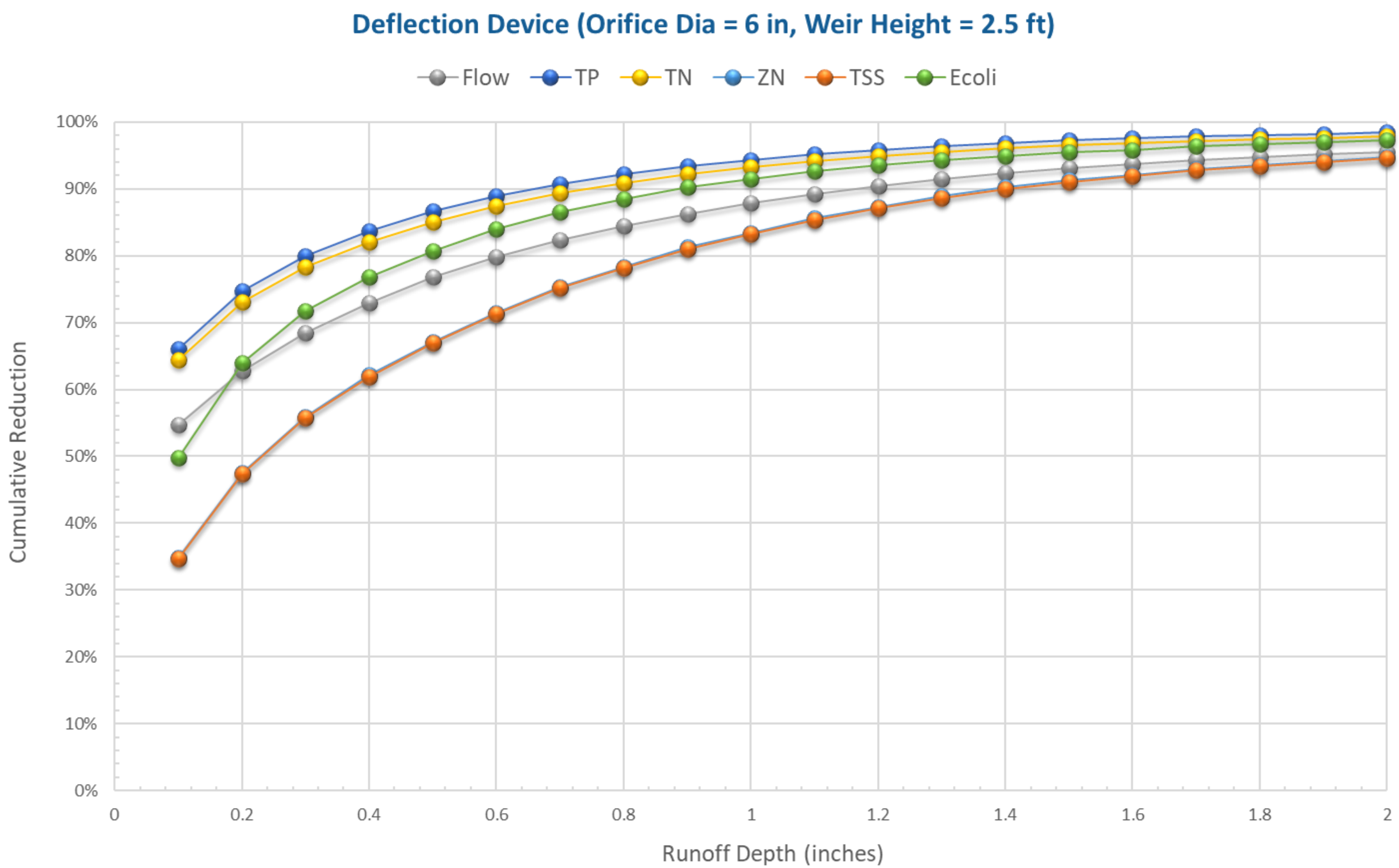

Figure 4-22. Deflection device (orifice diameter = 6 in, weir height = 2.5 ft) performance curve.

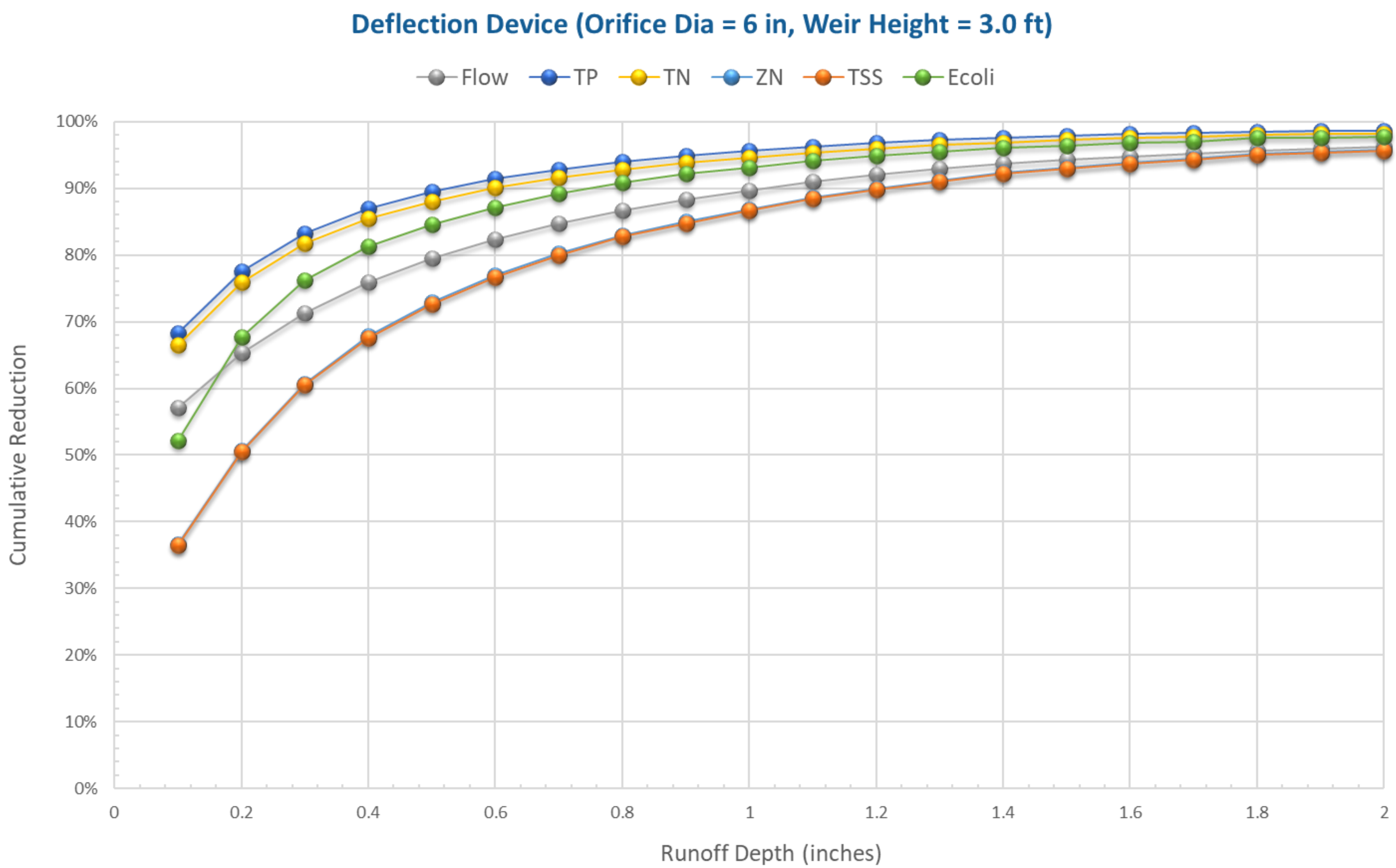

Figure 4-23. Deflection device (orifice diameter = 6 in, weir height = 3.0 ft) performance curve.

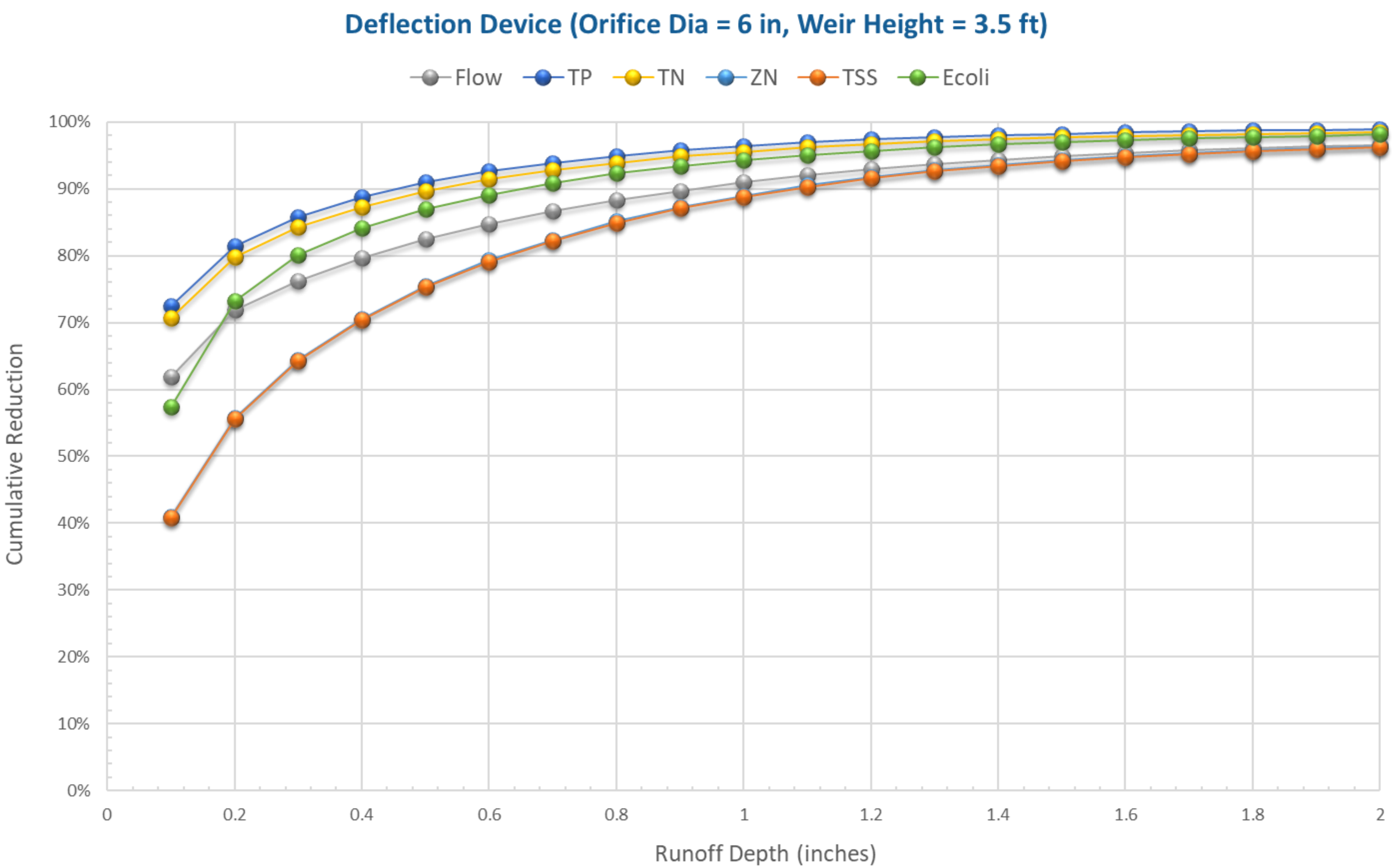

Figure 4-24. Deflection device (orifice diameter = 6 in, weir height = 3.5 ft) performance curve.

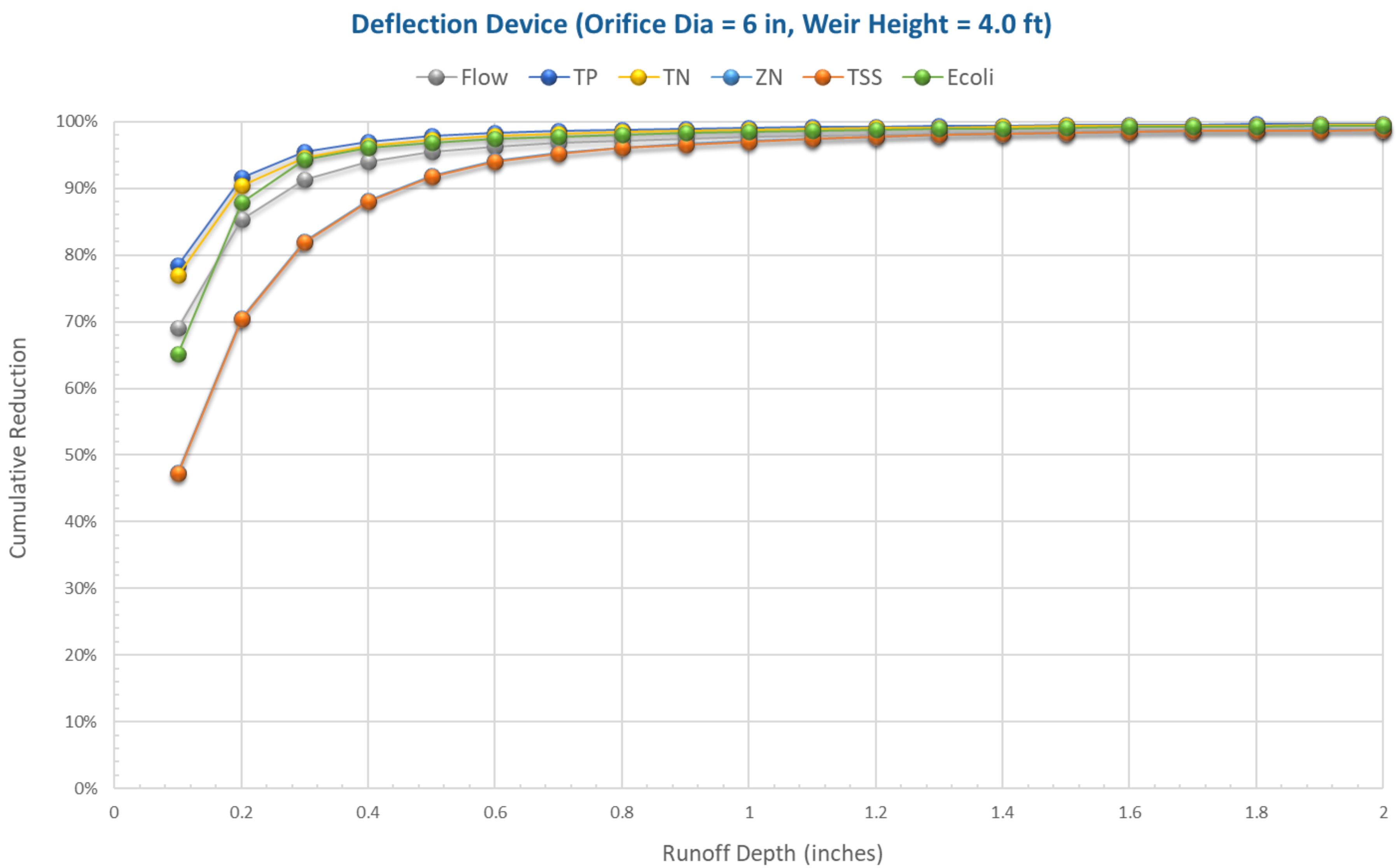

Figure 4-25. Deflection device (orifice diameter = 6 in, weir height = 4.0 ft) performance curve.

4.6 9-inch Orifice Diameter with Varying Weir Height

The performance curves in Figure 4-26 to Figure 4-33 illustrate the impact of varying weir height (i.e., the amount of temporary storage) with a fixed orifice size (9-in). Weir height was varied with a 0.5-ft increment between 0.5-ft and 4-ft. These curves show a similar trend as seen in 6-in orifice size but with relatively higher performance due to an increase in orifice size.

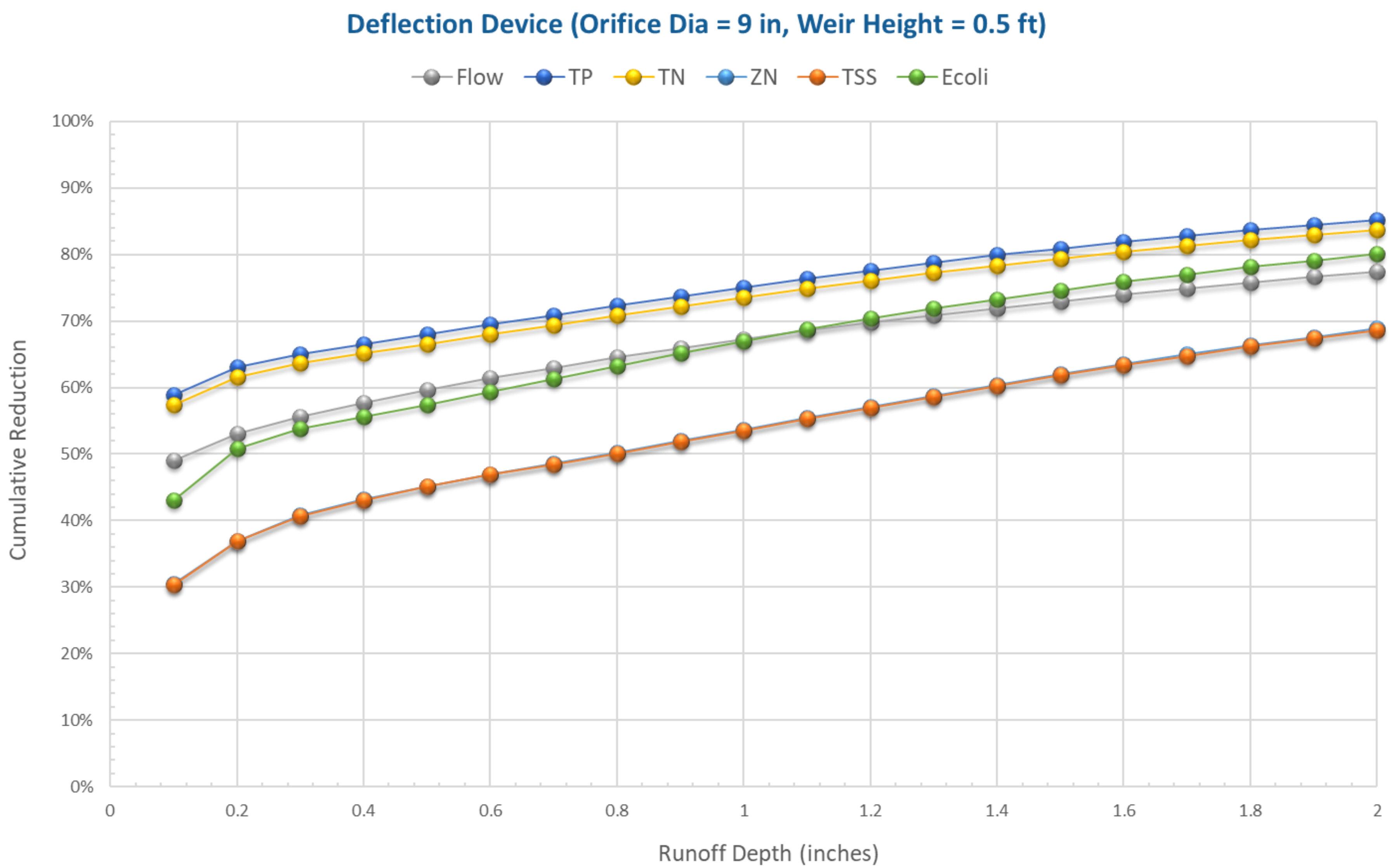

Figure 4-26. Deflection device (orifice diameter = 9 in, weir height = 0.5 ft) performance curve.

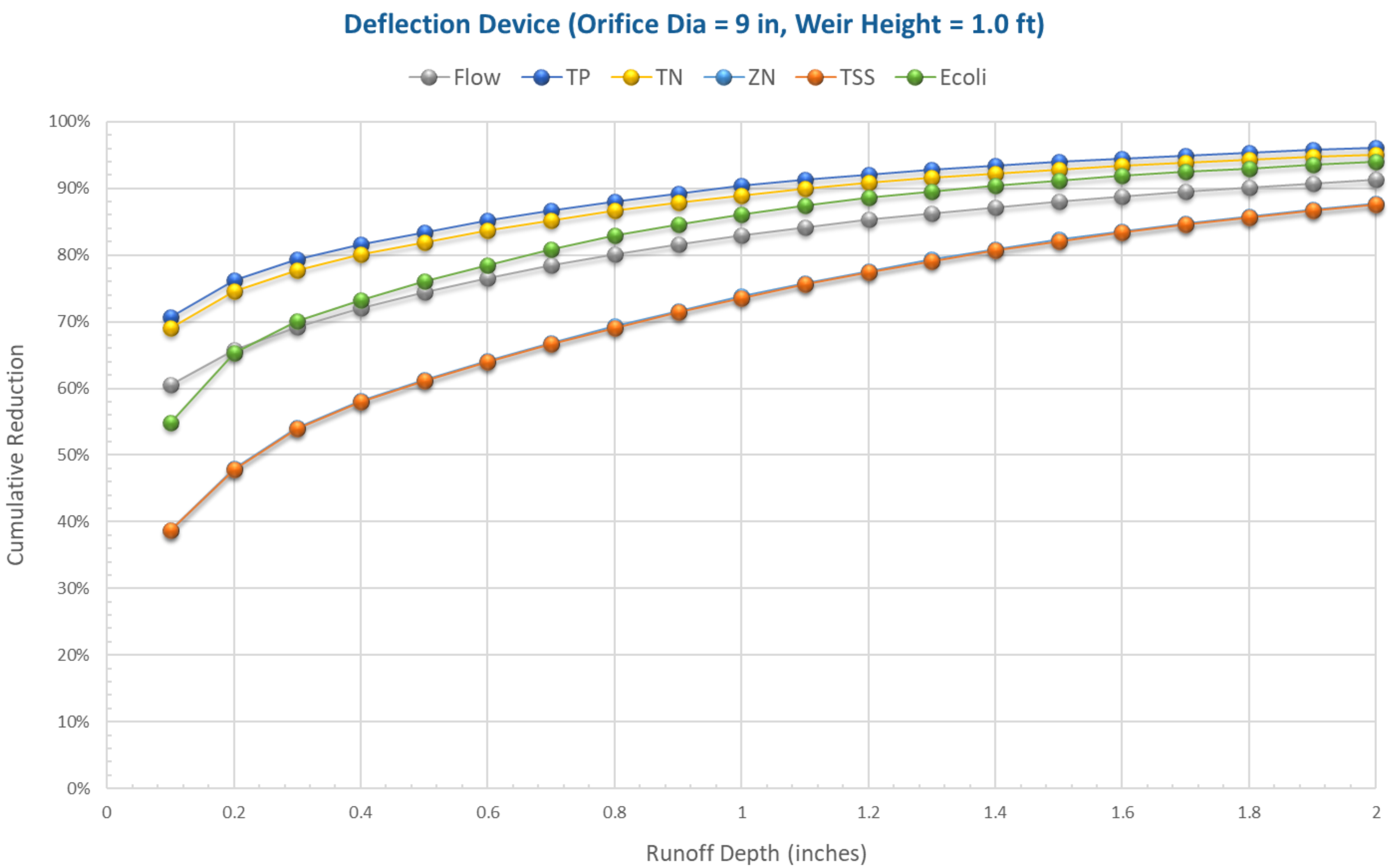

Figure 4-27. Deflection device (orifice diameter = 9 in, weir height = 1.0 ft) performance curve.

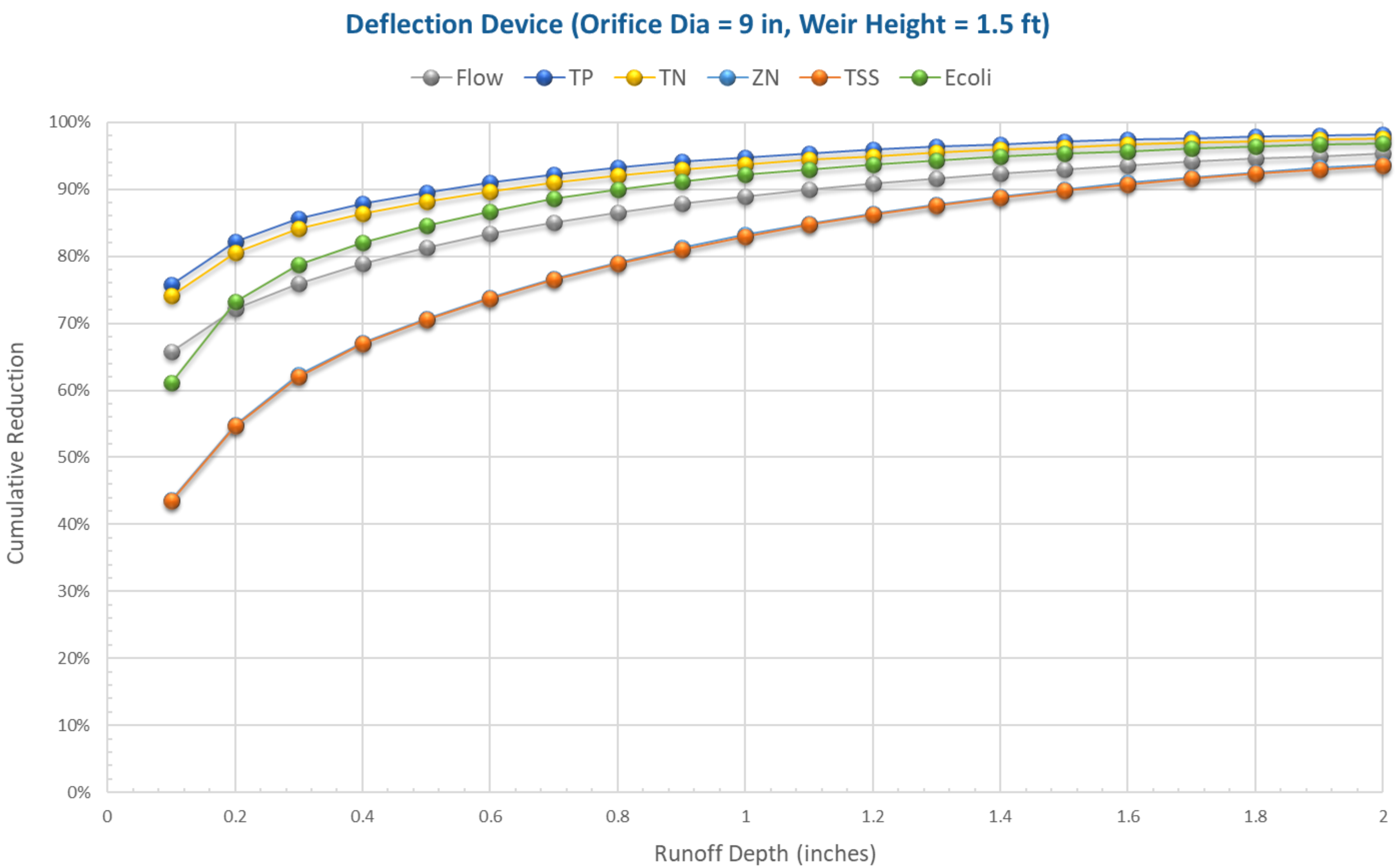

Figure 4-28. Deflection device (orifice diameter = 9 in, weir height = 1.5 ft) performance curve.

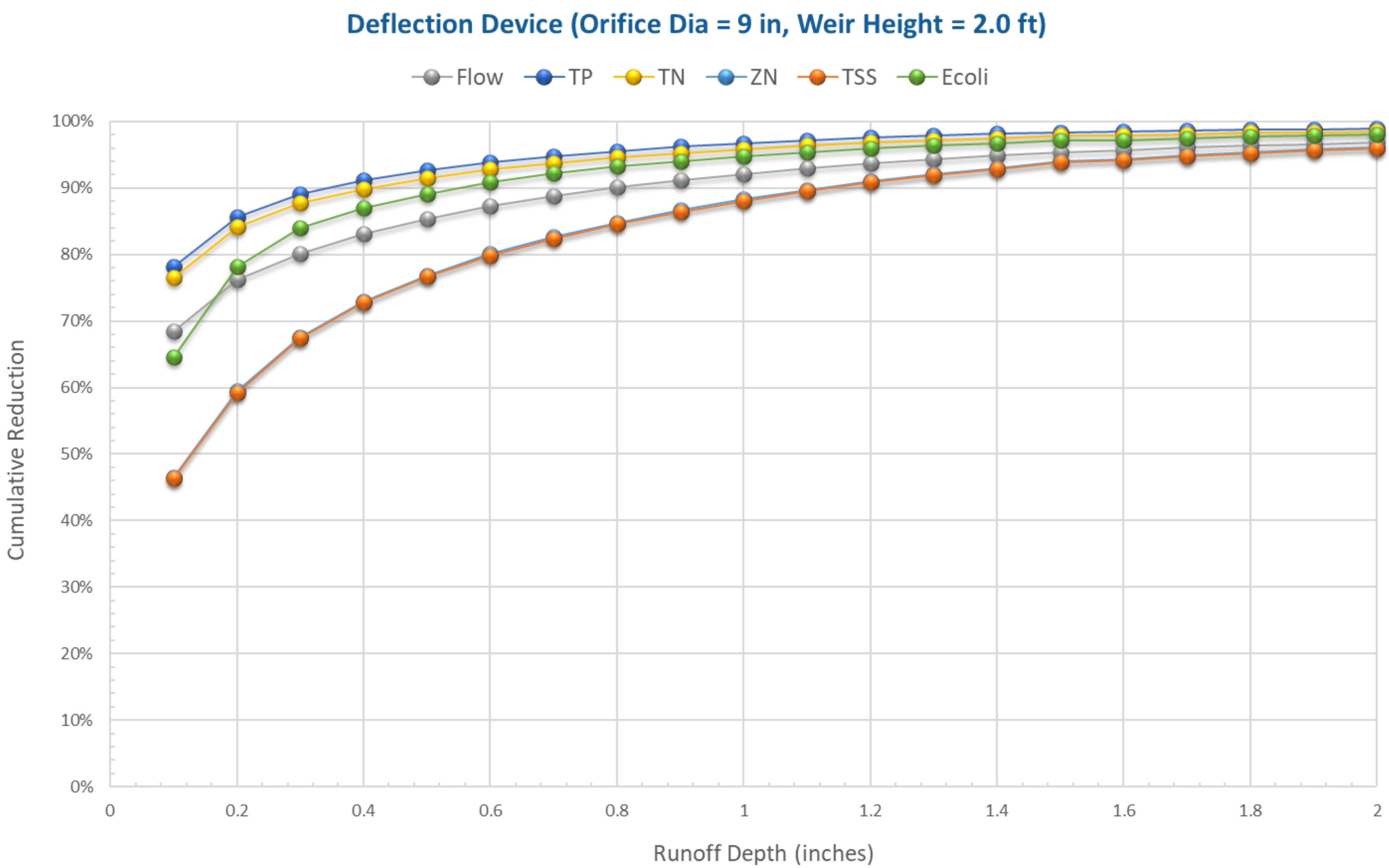

Figure 4-29. Deflection device (orifice diameter = 9 in, weir height = 2.0 ft) performance curve.

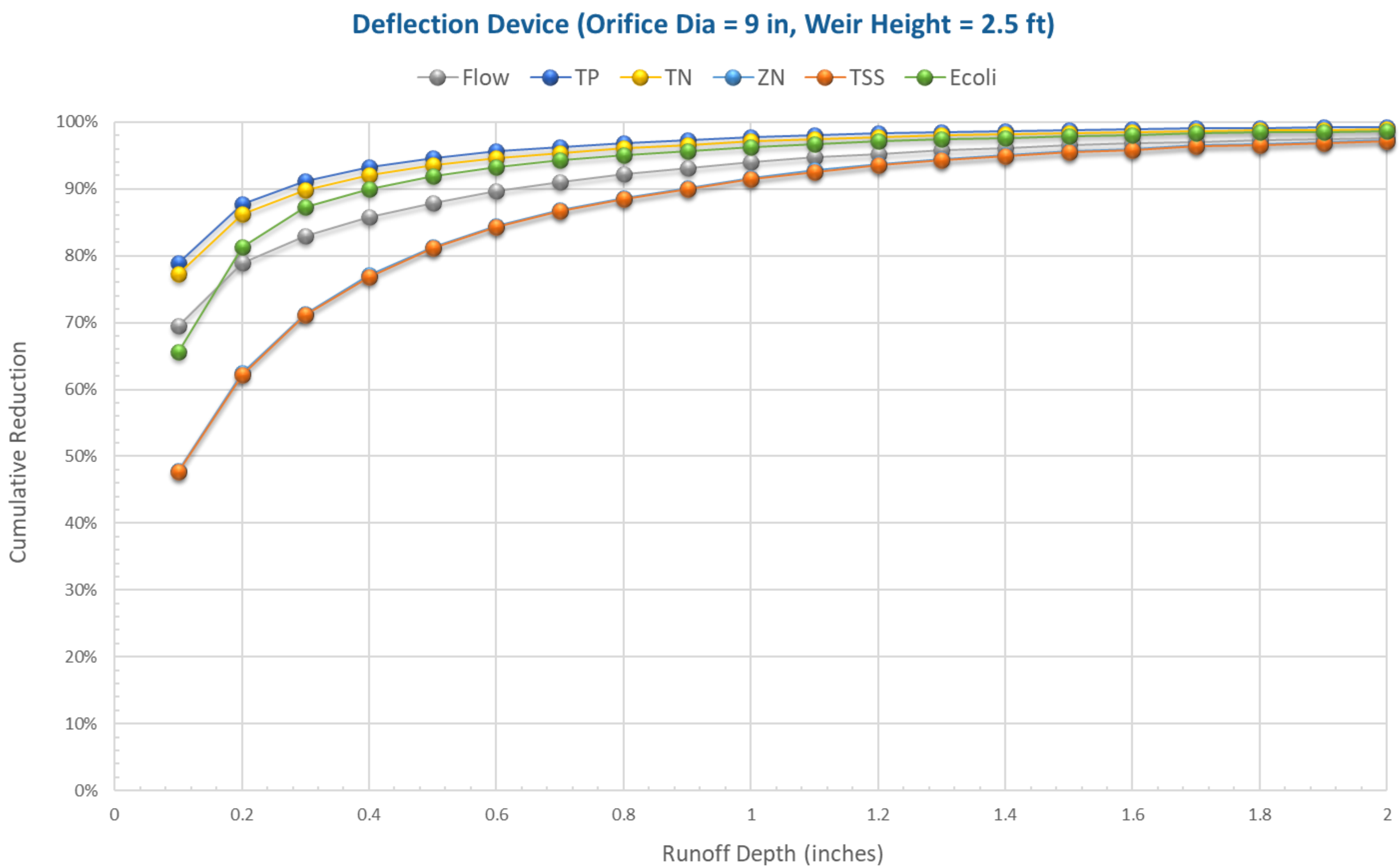

Figure 4-30. Deflection device (orifice diameter = 9 in, weir height = 2.5 ft) performance curve.

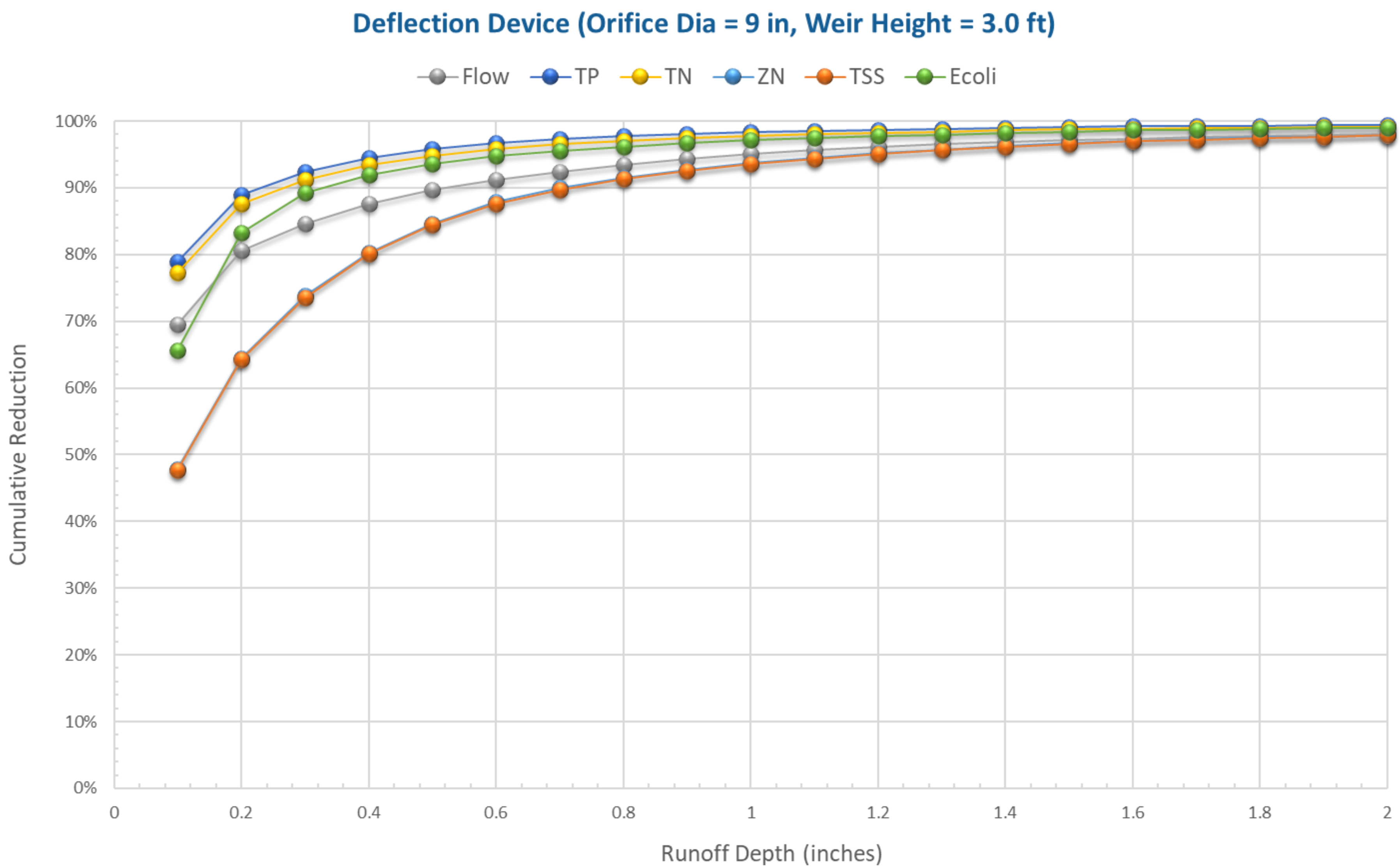

Figure 4-31. Deflection device (orifice diameter = 9 in, weir height = 3.0 ft) performance curve.

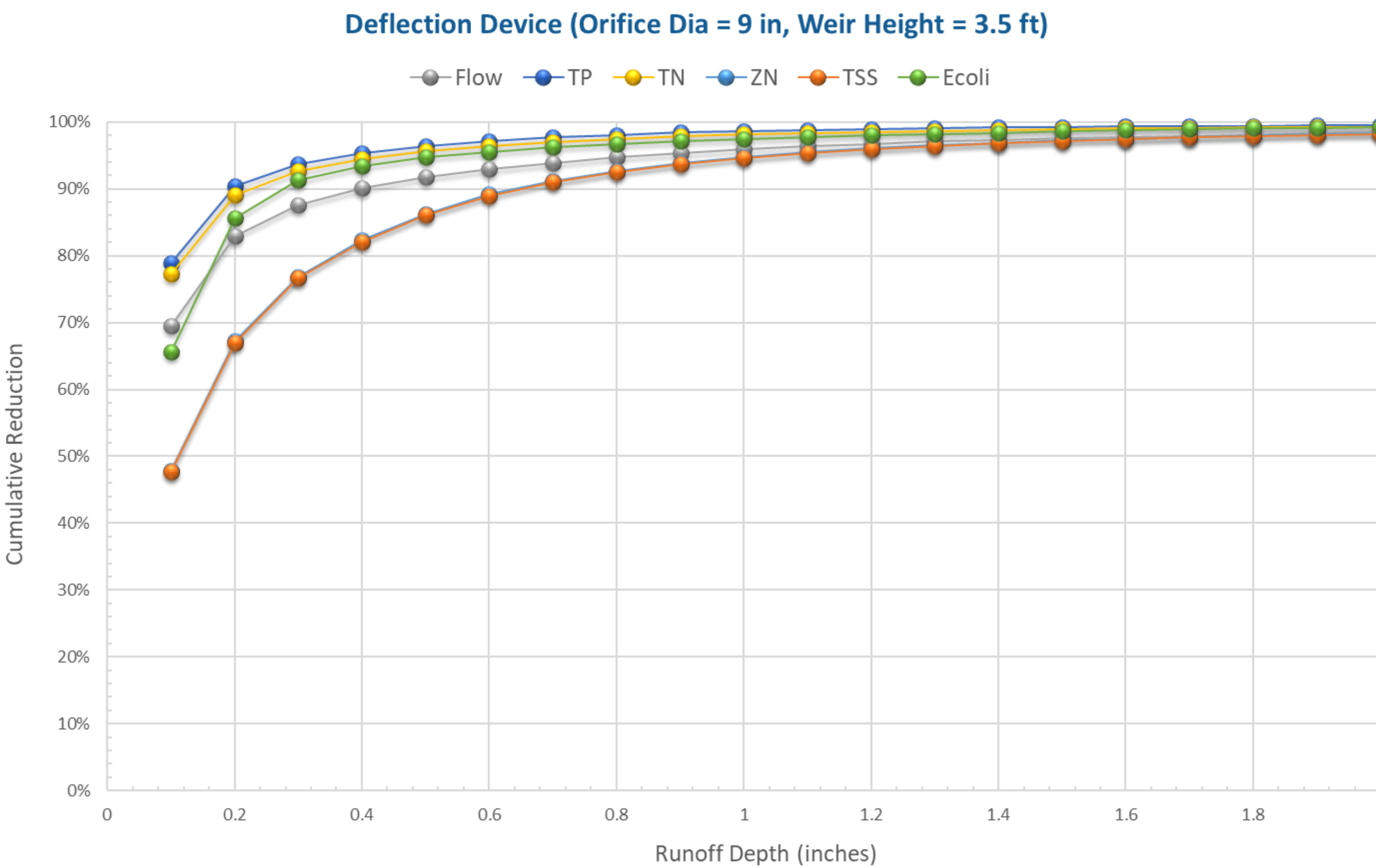

Figure 4-32. Deflection device (orifice diameter = 9 in, weir height = 3.5 ft) performance curve.

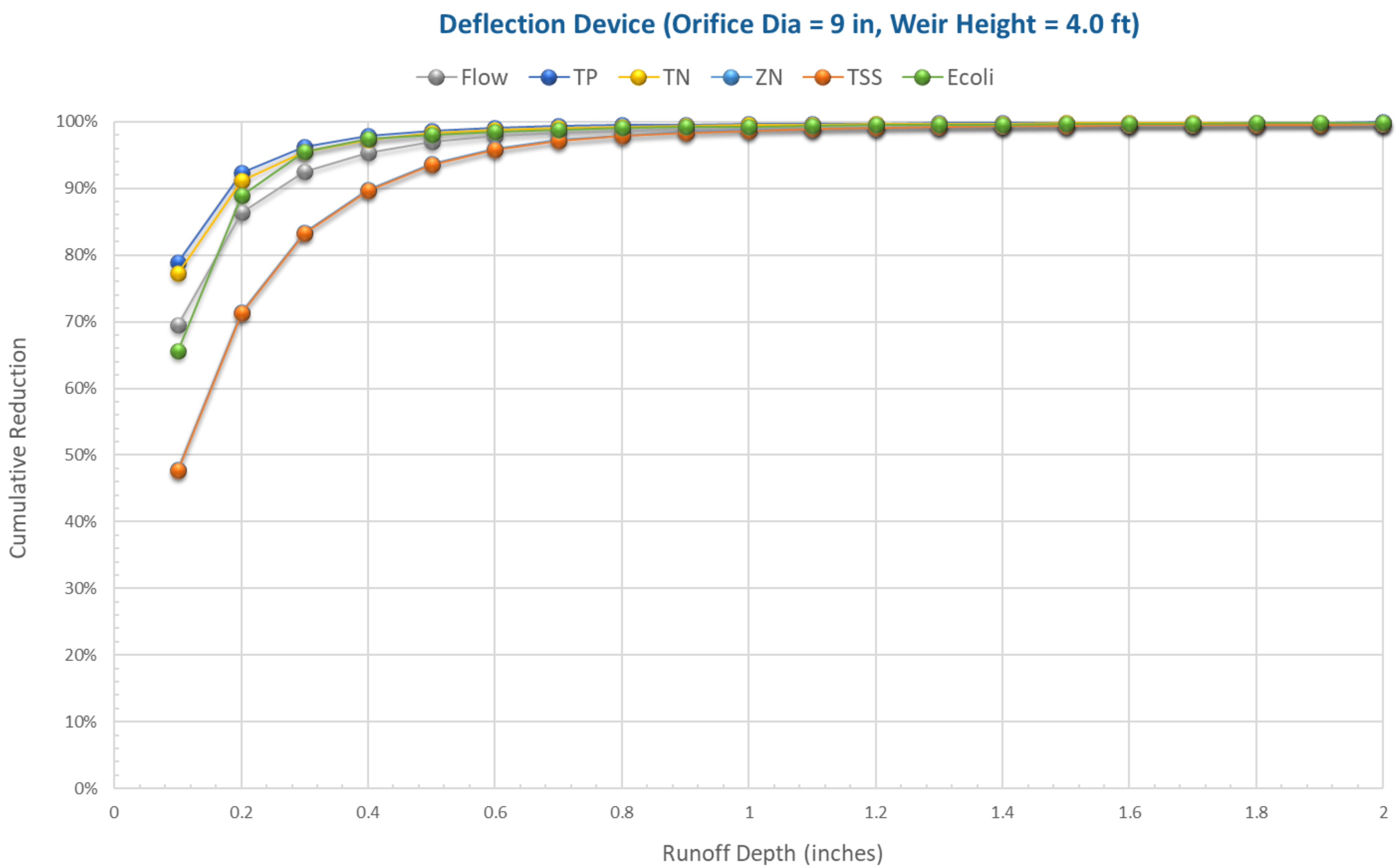

Figure 4-33. Deflection device (orifice diameter = 9 in, weir height = 4.0 ft) performance curve.

4.7 12-inch Orifice Diameter with Varying Weir Height

The performance curves in Figure 4-34 to Figure 4-39 illustrate the impact of varying weir height (i.e., the amount of temporary storage) with a fixed orifice size (12-in). Weir height was varied with a 0.5-ft increment between 0.5-ft and 3-ft. Given the relatively large orifice size, these curves quickly flatten out with increasing weir height. At 3-ft, the curves are essentially maxed out and curves for greater weir heights are not necessary.

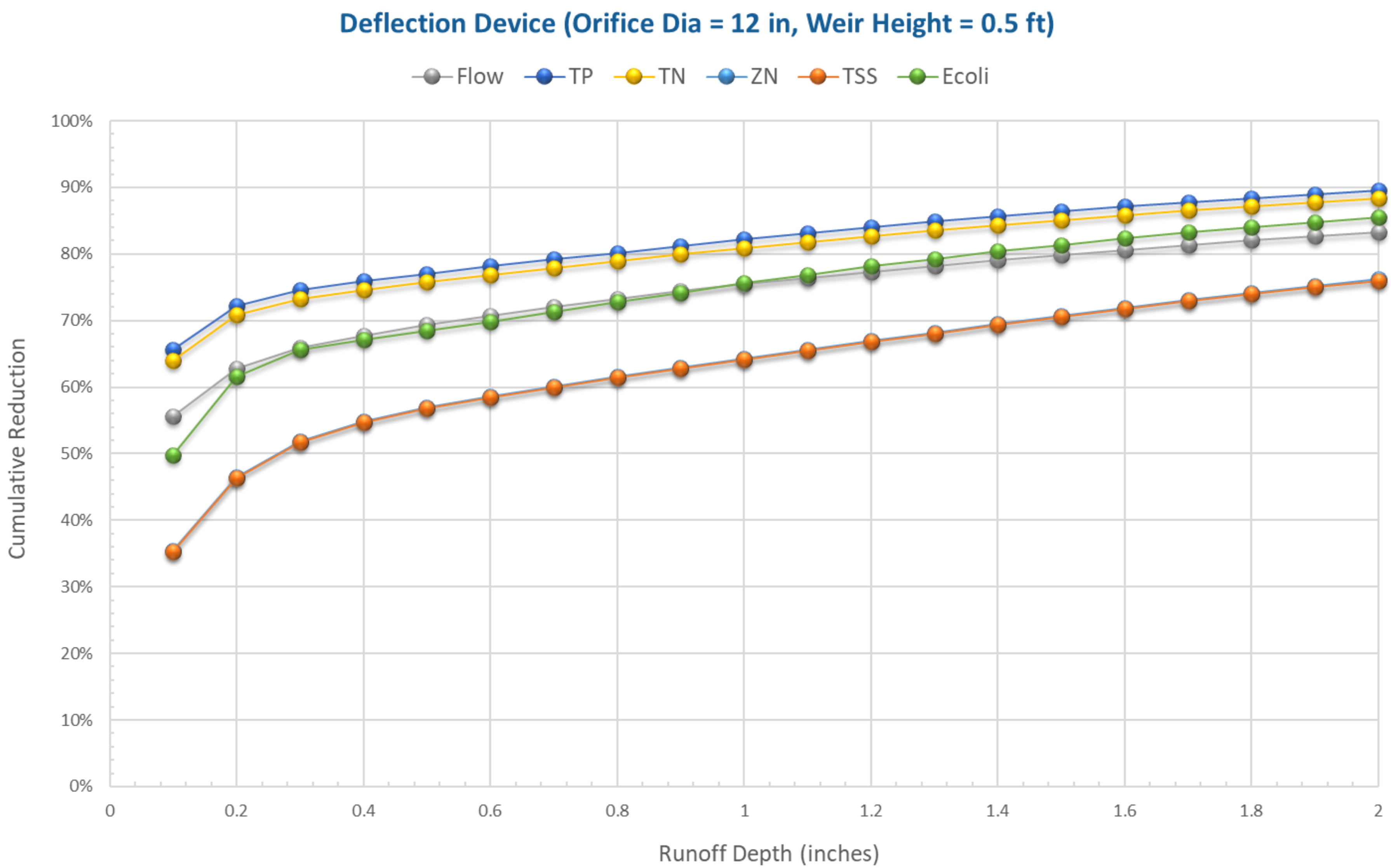

Figure 4-34. Deflection device (orifice diameter = 12 in, weir height = 0.5 ft) performance curve.

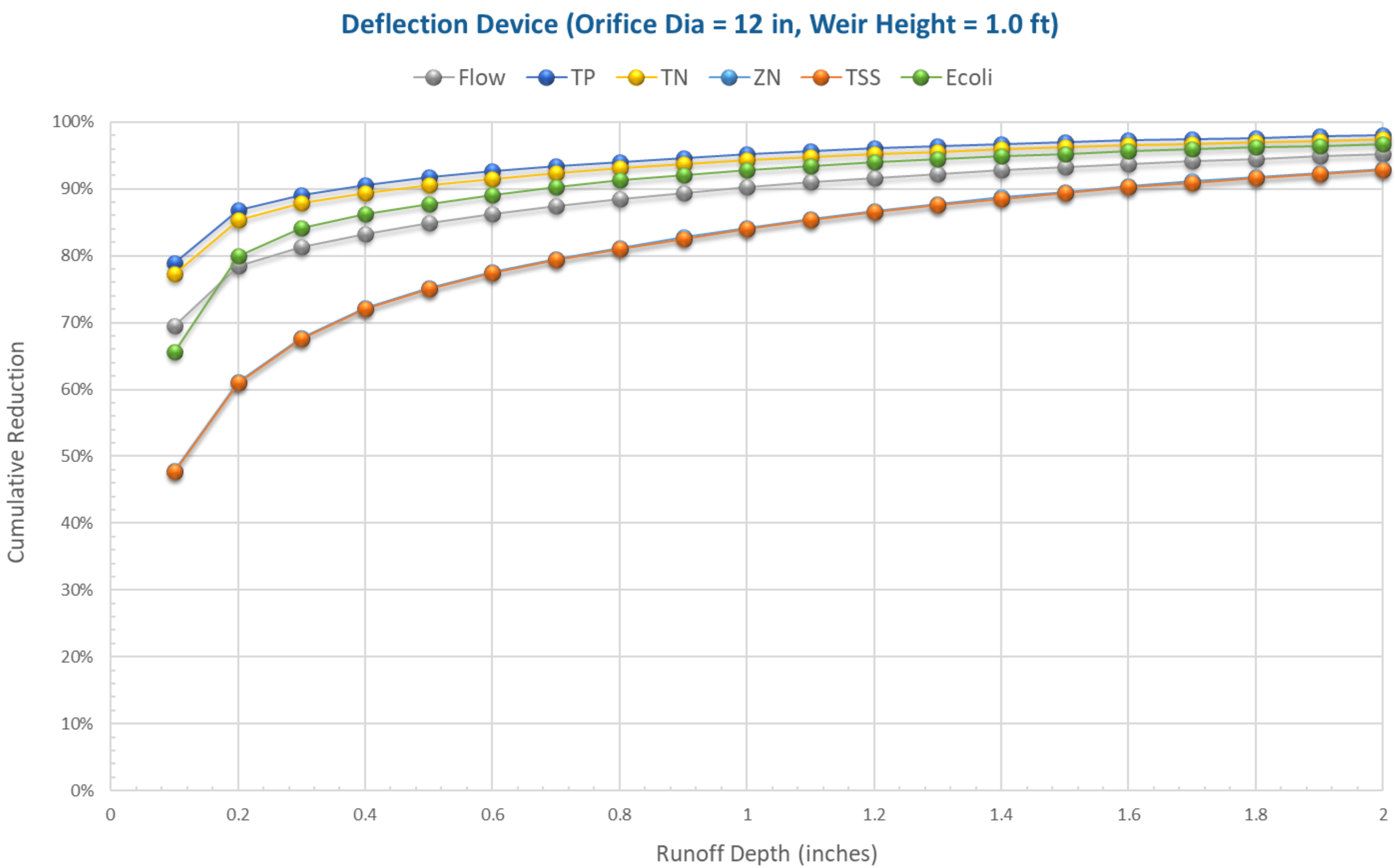

Figure 4-35. Deflection device (orifice diameter = 12 in, weir height = 1.0 ft) performance curve.

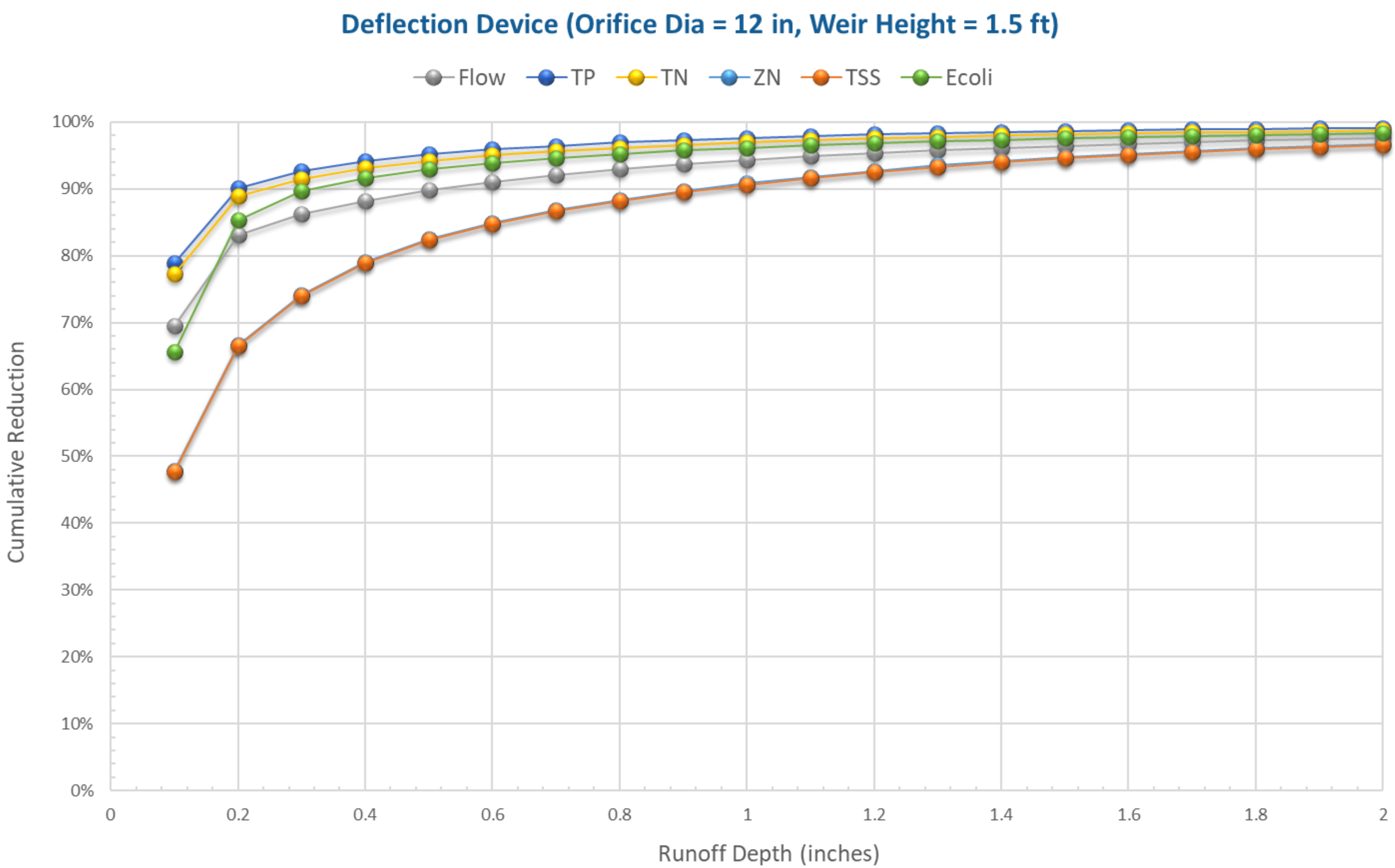

Figure 4-36. Deflection device (orifice diameter = 12 in, weir height = 1.5 ft) performance curve.

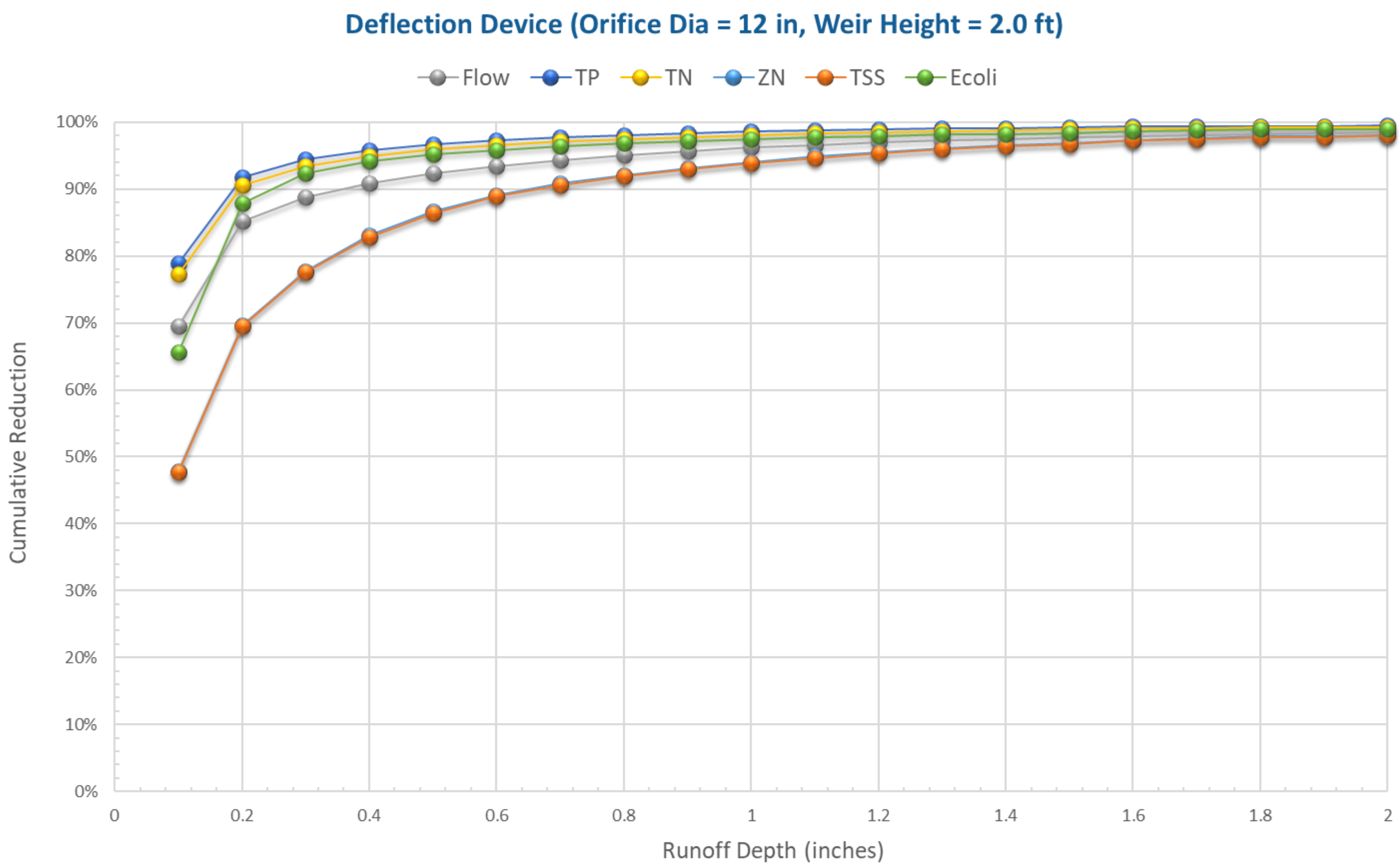

Figure 4-37. Deflection device (orifice diameter = 12 in, weir height = 2.0 ft) performance curve.

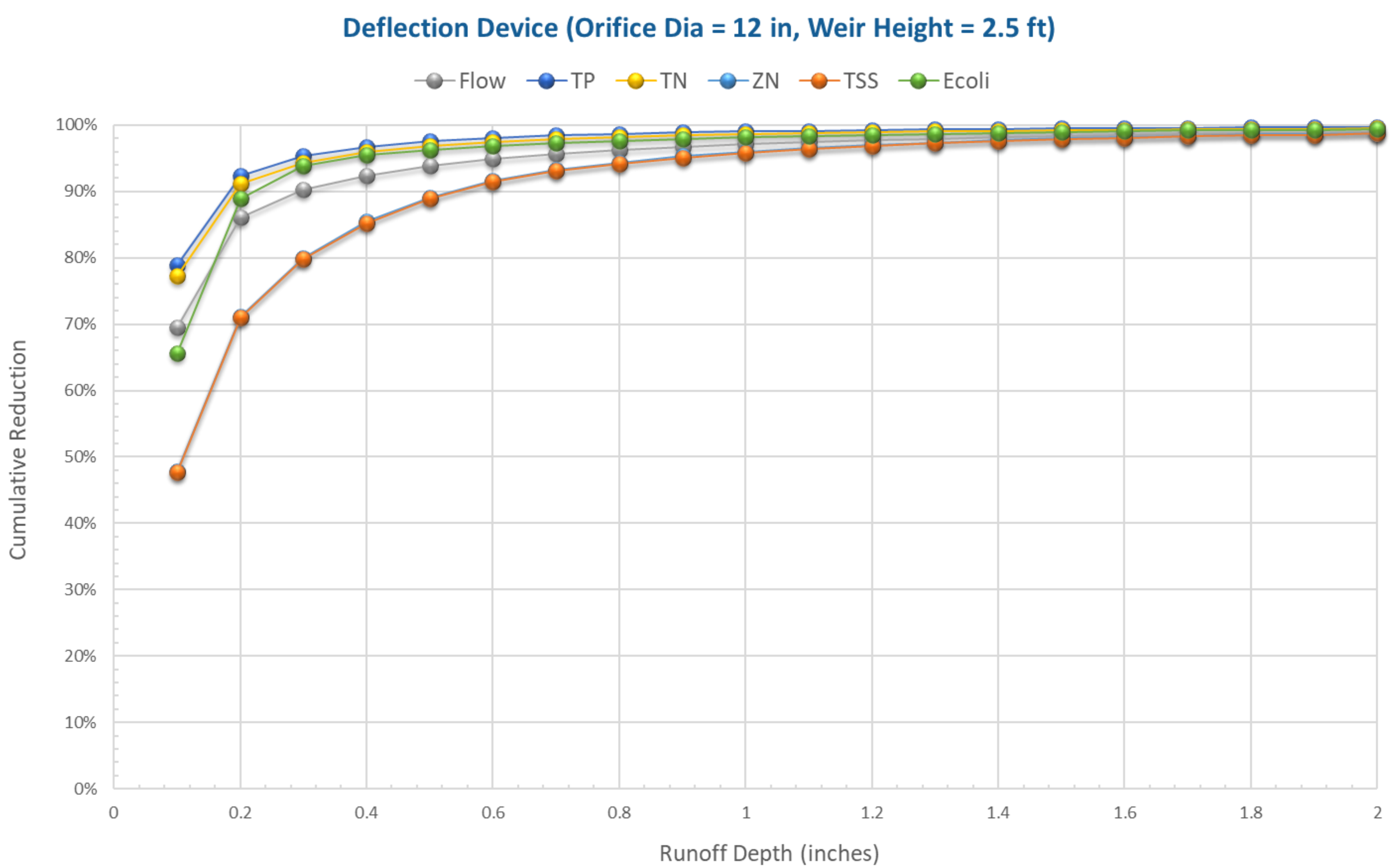

Figure 4-38. Deflection device (orifice diameter = 12 in, weir height = 2.5 ft) performance curve.

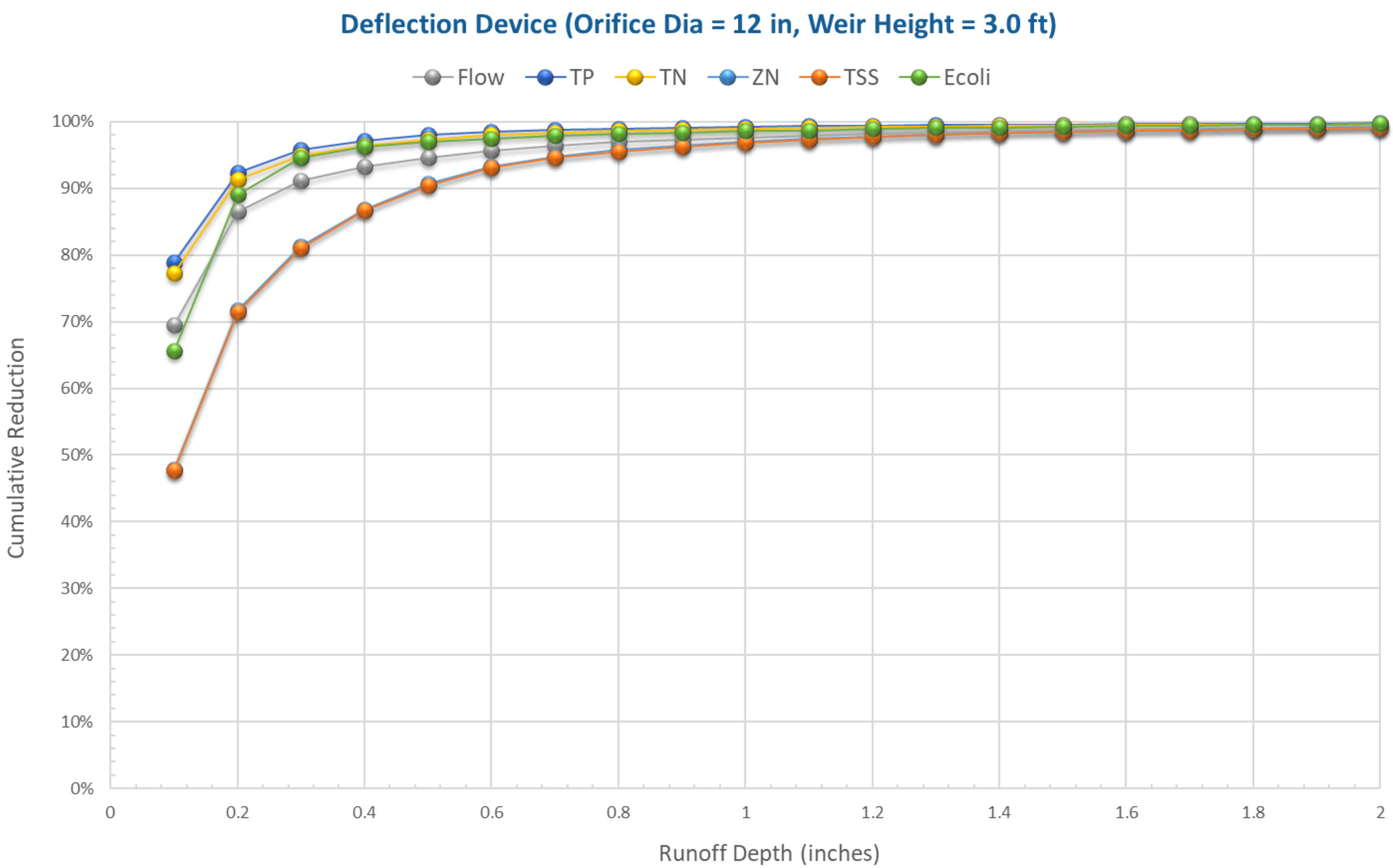

Figure 4-39. Deflection device (orifice diameter = 12 in, weir height = 3.0 ft) performance curve.

4.8 15-inch Orifice Diameter with Varying Weir Height

The performance curves in Figure 4-40 to Figure 4-43 illustrate the impact of varying weir height (i.e., the amount of temporary storage) with a fixed orifice size (15-in). Weir height was varied with a 0.5-ft increment between 0.5-ft and 2-ft. Given the relatively large orifice size, these curves quickly flatten out with increasing weir height. At 2-ft, the curves are essentially maxed out and curves for greater weir heights are not necessary.

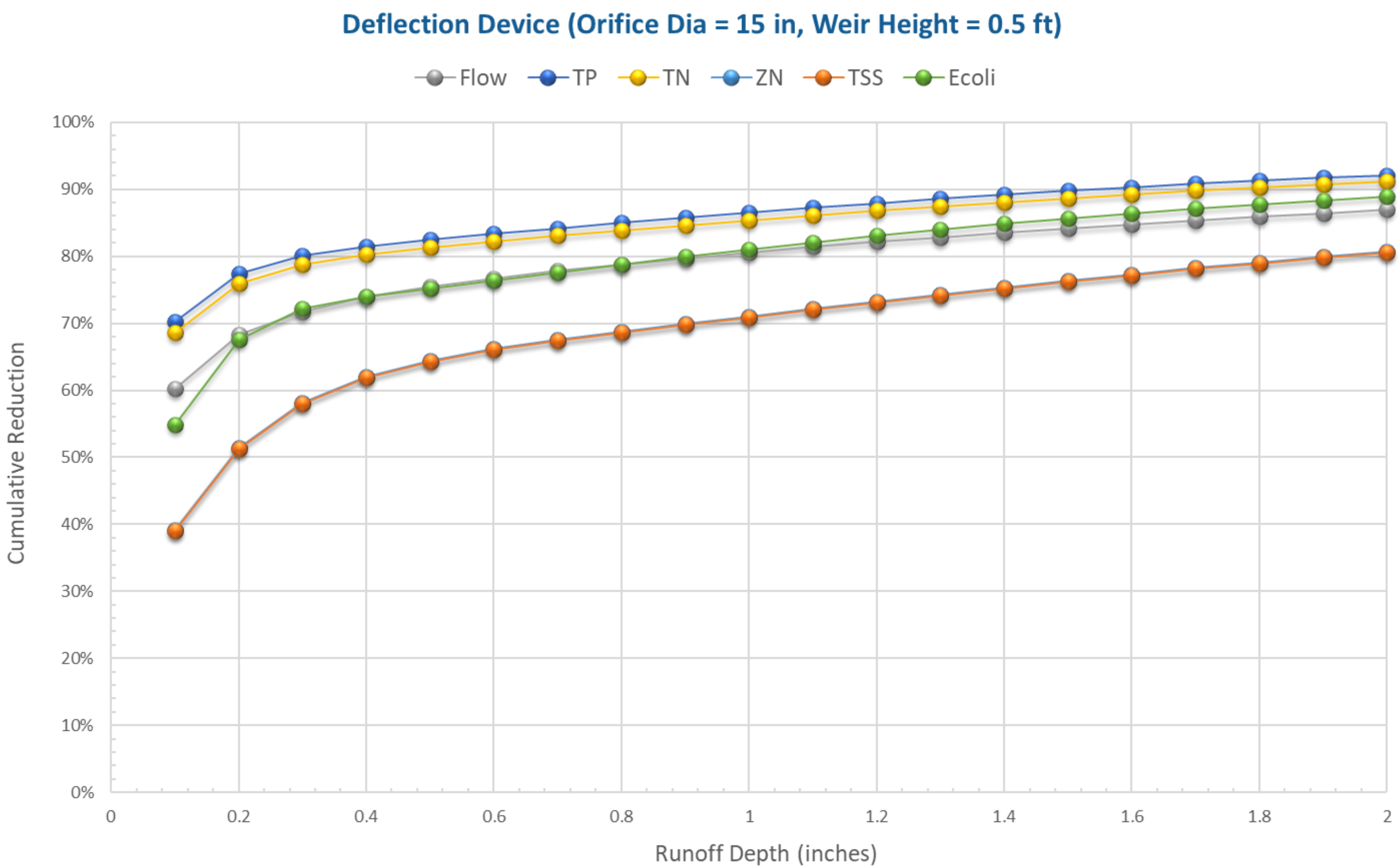

Figure 4-40. Deflection device (orifice diameter = 15 in, weir height = 0.5 ft) performance curve.

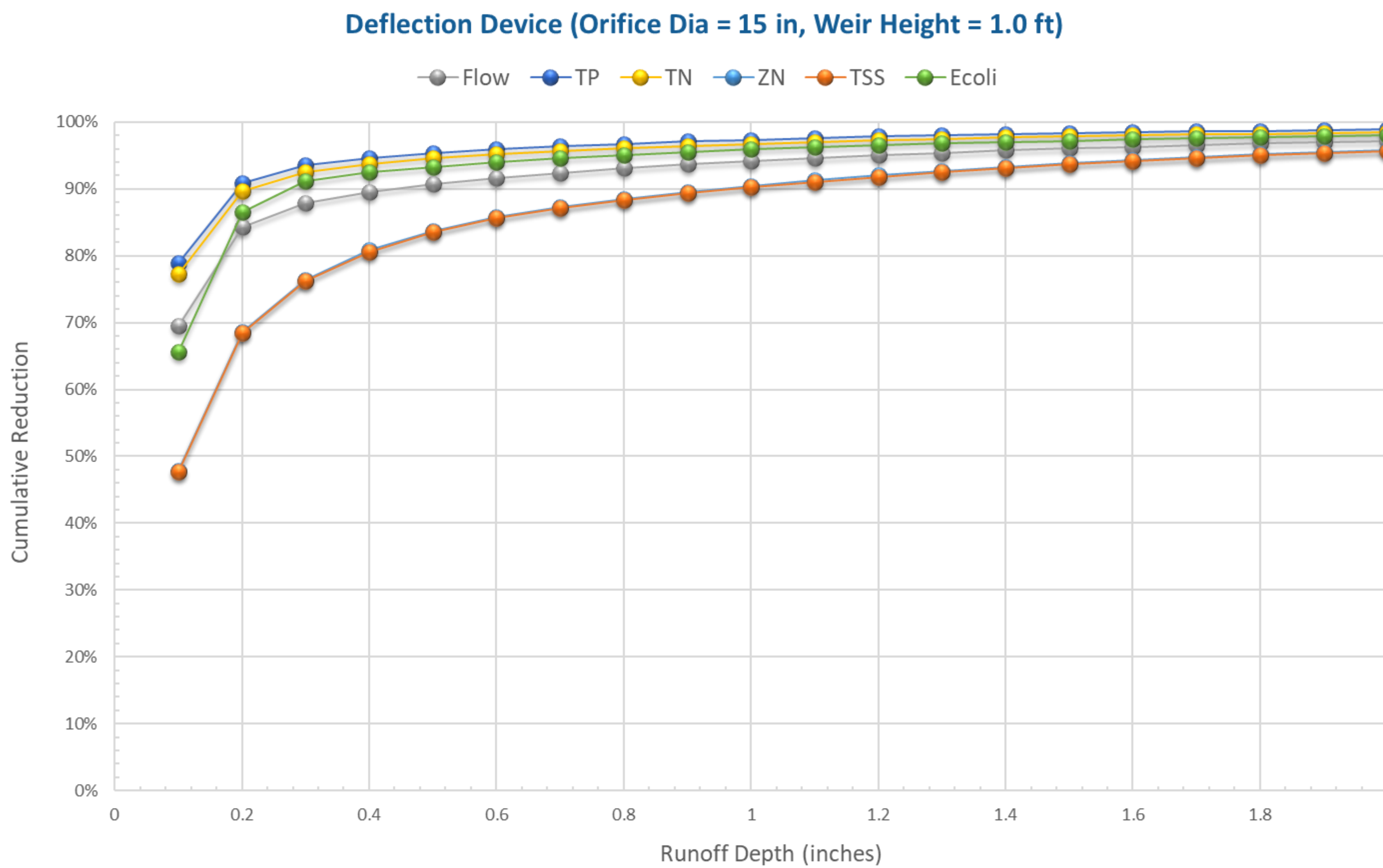

Figure 4-41. Deflection device (orifice diameter = 15 in, weir height = 1.0 ft) performance curve.

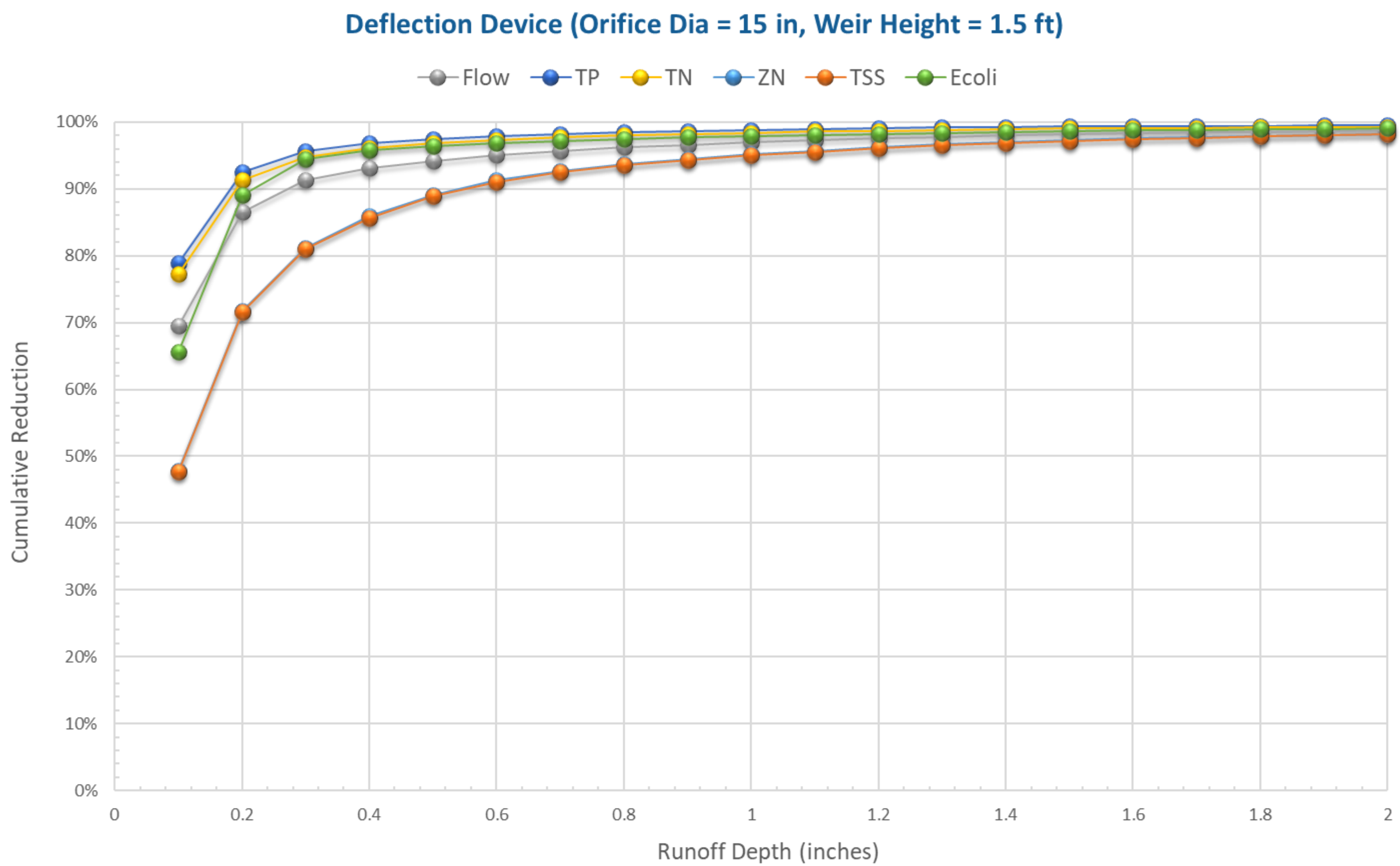

Figure 4-42. Deflection device (orifice diameter = 15 in, weir height = 1.5 ft) performance curve.

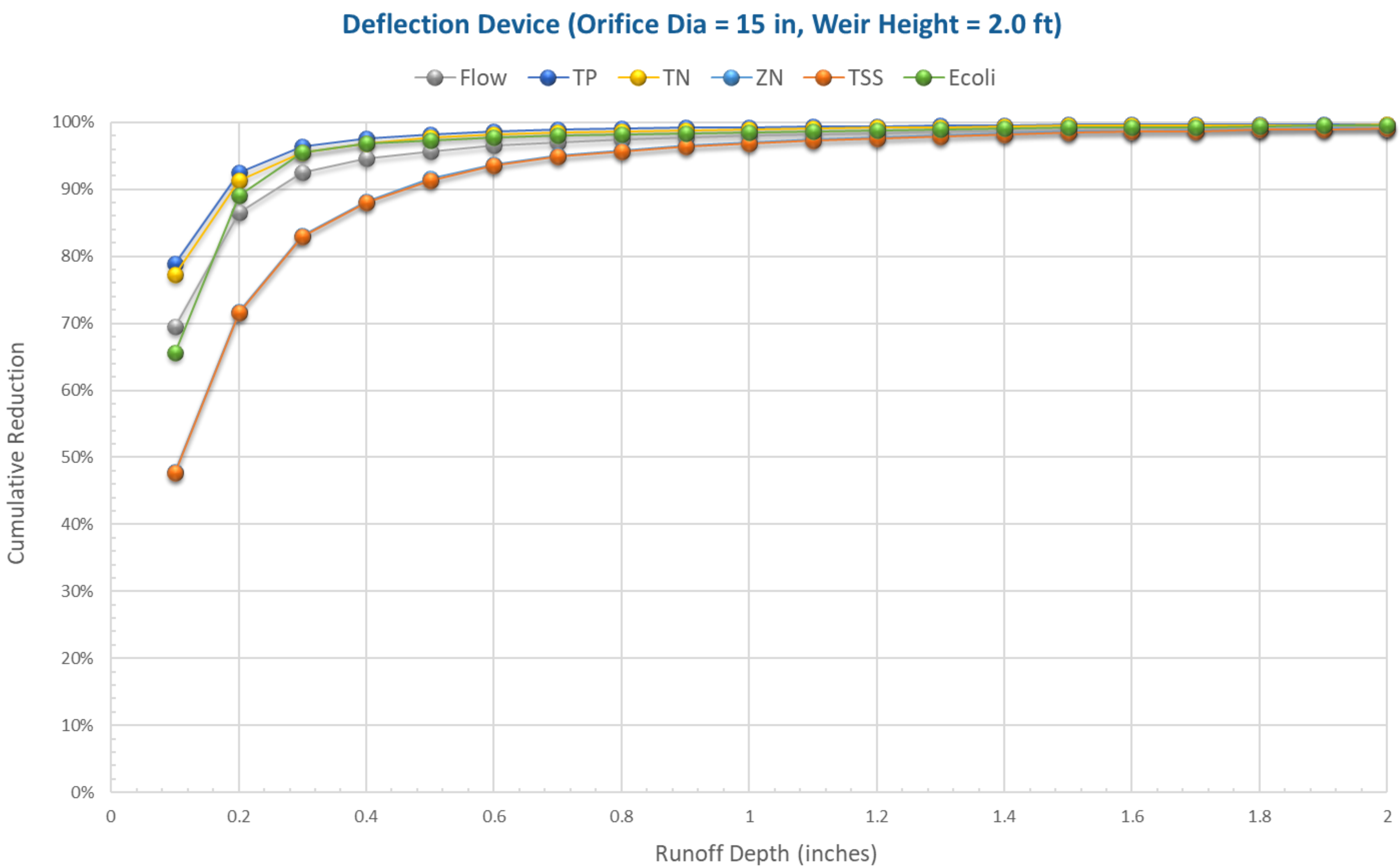

Figure 4-43. Deflection device (orifice diameter = 15 in, weir height = 2.0 ft) performance curve.

4.9 18-inch Orifice Diameter with Varying Weir Height

The performance curves in Figure 4-44 to Figure 4-46 illustrate the impact of varying weir height (i.e., the amount of temporary storage) with a fixed orifice size (18-in). Weir height was varied with a 0.5-ft increment between 0.5-ft and 1.5-ft. Given the relatively large orifice size, these curves quickly flatten out with increasing weir height. At 1.5-ft, the curves are essentially maxed out and curves for greater weir heights are not necessary.

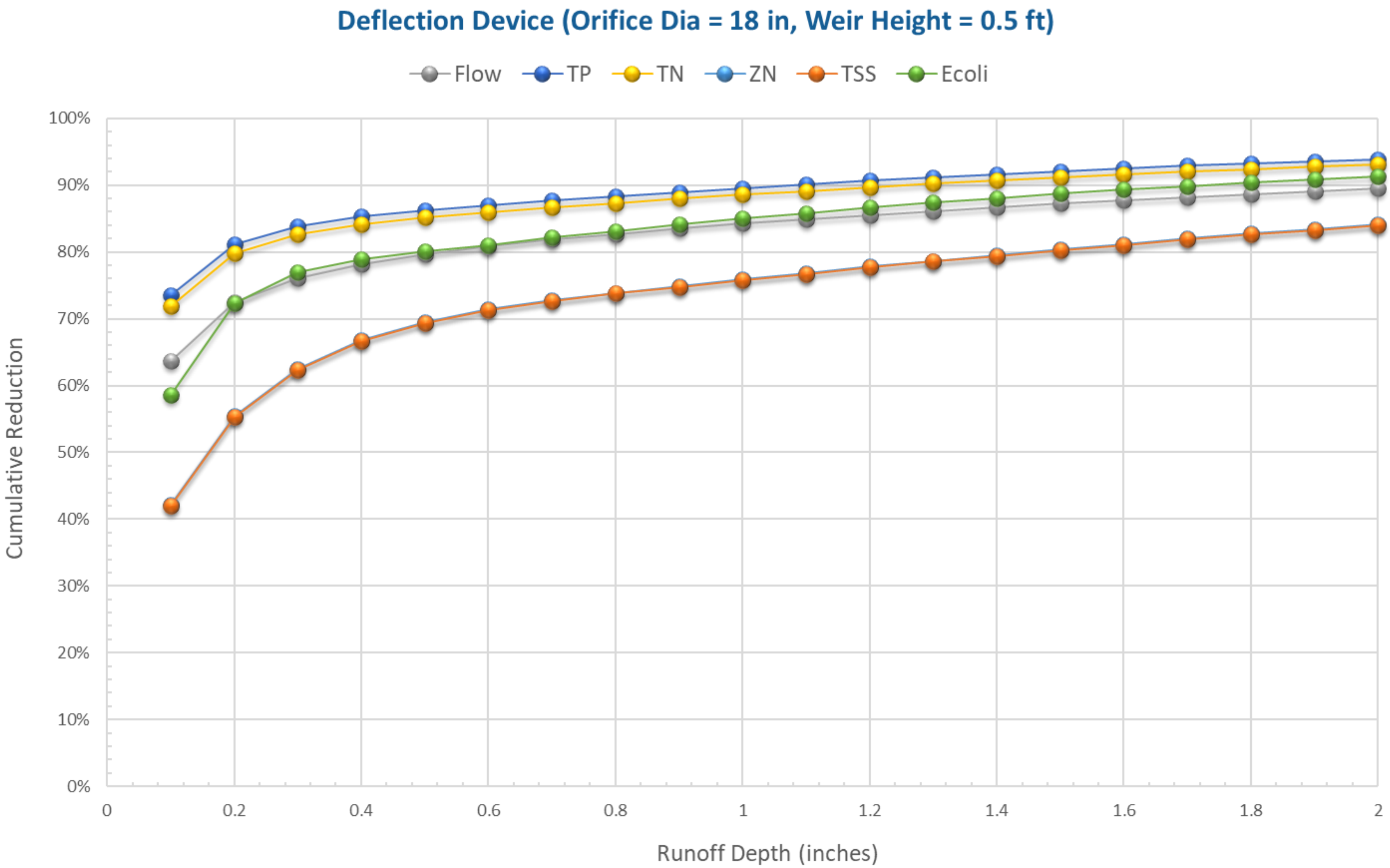

Figure 4-44. Deflection device (orifice diameter = 18 in, weir height = 0.5 ft) performance curve.

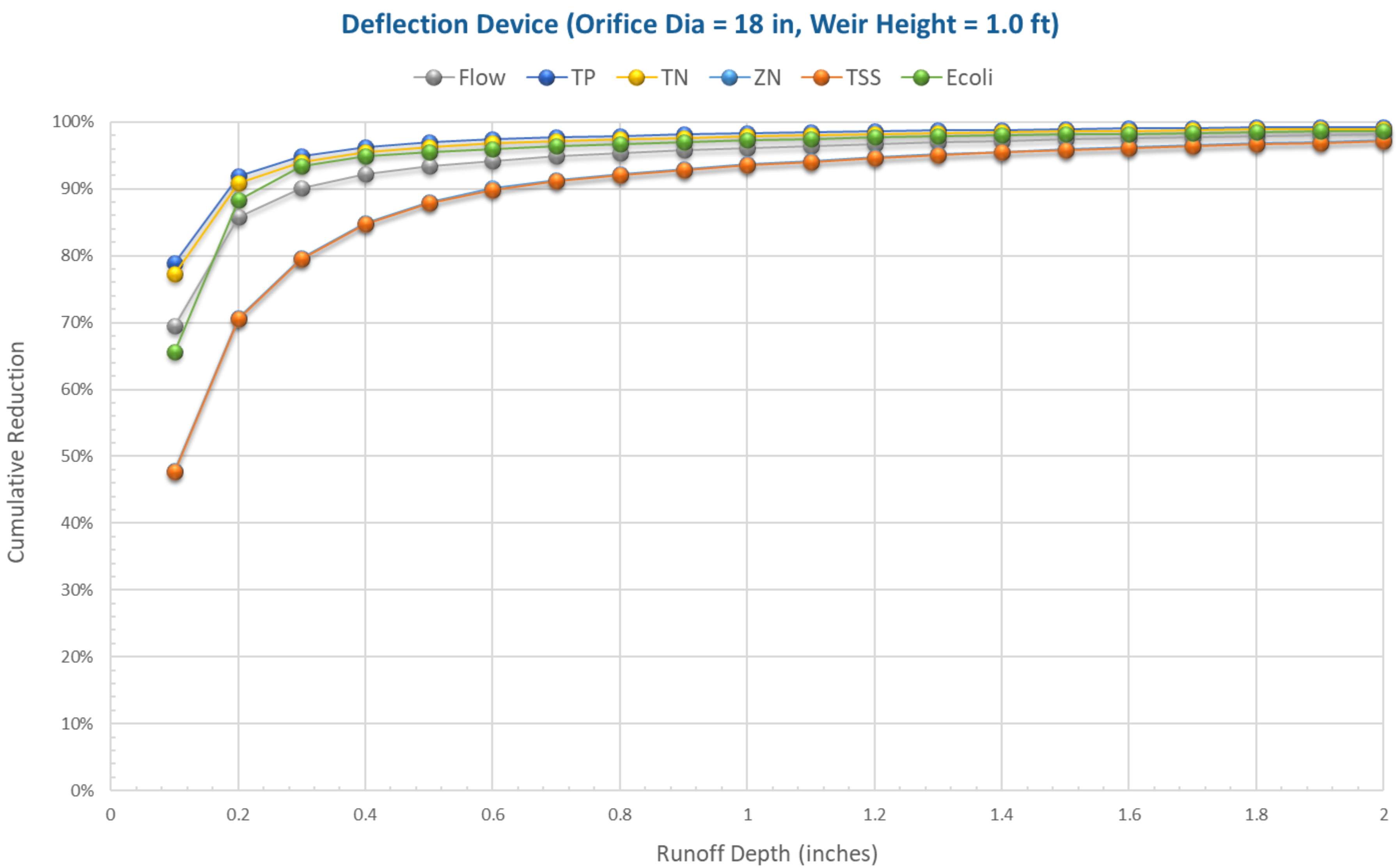

Figure 4-45. Deflection device (orifice diameter = 18 in, weir height = 1.0 ft) performance curve.

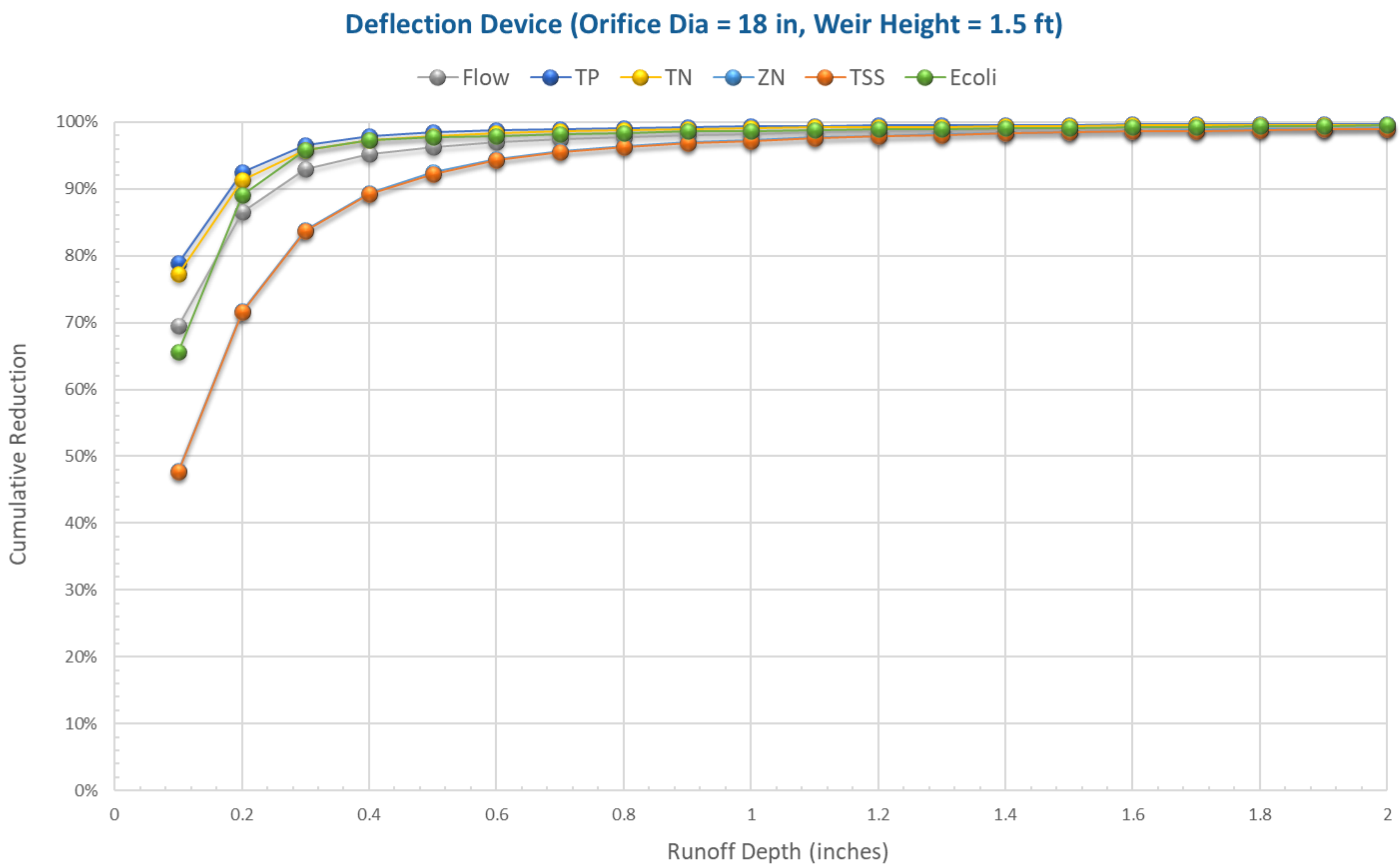

Figure 4-46. Deflection device (orifice diameter = 18 in, weir height = 1.5 ft) performance curve.

5 SUMMARY

This technical memo built upon the configuration and calibration of the Talbot sewer deflection device in Cambridge, MA within the EPA R1 Opti-Tool software package (Paradigm Environmental, 2024) and describes the development of deflection device curves suitable for planning and crediting purposes. A total of 45 sets of performance curves, each describing the percentage reduction in stormwater flow and 5 pollutants (TP, TN, TSS, Zn, and Bacteria), were developed based on 31 years of continuous simulation using the Opti-Tool HRU time series. One set of performance curves represents the performance of the existing Talbot deflection device with varying runoff capture depths. Fifteen sets of curves represent inline flow diversion scenarios with no weir to create temporary storage and diversion controlled by orifice size and pipe slope. The 29 remaining curves represent a range of scenarios based on varied orifice diameter and weir height. These 44 curves can be used to estimate the performance of other deflection devices and can be applied using the following steps:

1. Delineate the deflection device drainage area (i.e., the upstream contributing area to the orifice structure) and calculate the directly connected impervious area (DCIA) within the drainage (ac).
2. Identify the stormwater network within the deflection device drainage area and create the F-table representing depth (foot) and storage capacity (acre-inch) based on the pipe dimensions.
3. Estimate runoff capture depth (inch) as the storage capacity divided by the DCIA.
4. Based on the device's configuration (i.e., inline diversion with no temporary storage or device with temporary storage), choose the appropriate performance curve based on the device characteristics (pipe slope, orifice diameter, weir height) and read the percentage reductions based on the estimated runoff capture depth. Curves should be chosen by picking the one closer to the lower end or by interpolating between two curves if necessary.

6 REFERENCES

City of Cambridge, Stantec, 2023. Water Quality Analysis Presentation 20231031_final.

Kleinfelder, Stantec, 2020. Cambridge port Stormwater Improvements: MWRA Underflow Modifications. City of Cambridge File Number 7113. Cambridge, MA.

Paradigm Environmental, 2024. Subtask 3A Technical Memorandum: Development of, and Modeling Approach for Conceptual Generic Representation of City of Cambridge, Ma Sewer Deflection Devices. Prepared for the U.S. Environmental Protection Agency.