

Univerzitet u Beogradu, Građevinski fakultet



Merenje protoka u otvorenim tokovima – Projektovanje mernog suženja



Merenja u hidrotehnici

6. Vežba

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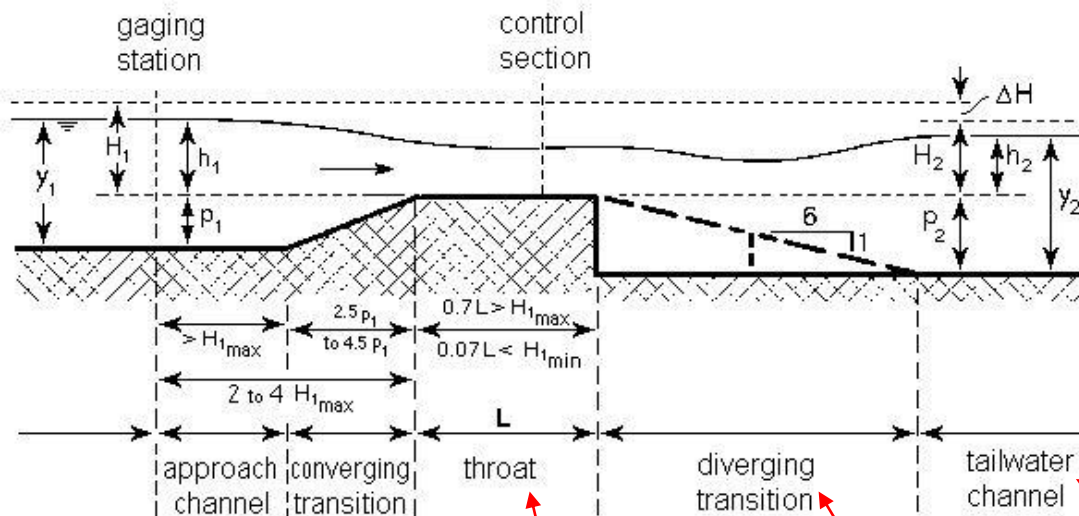
MERENJE OSNOVNIH VELIČINA U HIDROTEHNICI

- Merenje pritiska: pjezorezistivni, kapacitivni, induktivni senzori
- Merenje nivoa vode: ultrazvučni senzori, senzori pritiska + preračunavanje
- Merenje brzine: UZV, EM, hot-wire i hot-film, ...
- Merenje protoka: volumetrijsko, UZV, EM, **suženja...**

+ merenje kvaliteta vode: pH, mutnoća, elektroprovodnost

MERENJE PROTOKA – MERNOSUŽENJE

Merno suženje – merenje protoka u otvorenim tokovima na osnovu merenja jedne ili dve dubine



Koju dubinu meriti i kako?

Prilazna – uzvodna deonica

Prelazna deonica

Grlo - suženje

Proširenje – vraćanje na geometriju kanala

Nizvodna deonica

MERENJE PROTOKA – MERNO SUŽENJE

Merno suženje – kako meriti protok preko dubine?

- Potrebno je ustanoviti koja dubina se meri i koja je funkcionalna zavisnost protoka od dubine
- Funkcionalna zavisnost $Q=f(h)$ poznata za kritičnu dubinu (preko Frudovog broja)
- Merno suženje omogućava formiranje kritične dubine h_{kr}
- **Da li se u suženju zna gde je tačno kritična dubina?!**

Ne znamo gde je tačno kritična dubina, ne možemo da je izmerimo, ali znamo da se javlja negde u suženju!!!

MERENJE PROTOKA – MERNO SUŽENJE

Merno suženje – kako meriti protok preko dubine?

- Ne meri se dubina u suženju, već se meri dubina negde uzvodno
- Miran režim uzvodno - manja neodređenost pri merenju dubine
- Funkcionalna zavisnost $Q=f(h_{uzv})$ – na osnovu Bernulijeve jednačine od preseka uzvodno do preseka u suženju
- Samo se uzima lokalni gubitak energije

MERENJE PROTOKA – MERNO SUŽENJE

Merno suženje – kako meriti protok preko dubine?

Cilj – meriti dubinu uzvodno h_1 , i na osnovu $Q=f(h_1)$ dobiti protok

$$h_1 + \frac{Q^2}{2gA_1^2} = h_2 + \frac{Q^2}{2gA_2^2} (1 + \xi)$$

$$Fr_{r,2} = \frac{Q^2 B_2}{gA_2^3} = 1$$



Kombinacijom ove dve jednačine i rešavanjem po h_1 dobija se funkcionalna zavisnost (jednoznačna veza) između protoka Q i dubine **uzvodno** od suženja h_1



$$Q = f(h_1)$$

Kriva protoka

h_1, h_2 – uzvodna dubina i dubina na suženju

Q – protok

A_1, A_2 – površine poprečnih preseka

ξ - koeficijent lokalnog gubitka na suženju

MERENJE PROTOKA – MERNO SUŽENJE

Kako isprojektovati merno suženje?

- Odrediti dužinu prilazne deonice, dužinu uzvodne prelazne deonice, dužinu suženja (i visinu praga u suženju), dužinu i nagib nizvodne prelazne deonice i eventualno dubinu ukopavanja nizvodne deonice
- Uslovi za projektovanje – da se u opsegu između minimalnog i maksimalnog predviđenog Q , i pri odgovarajućim nizvodnim graničnim uslovima javi nepotopljeno tečenje u suženju

MERENJE PROTOKA – MERNO SUŽENJE

Kako isprojektovati merno suženje?

- Da bi projekat bio kompletan, potrebno je predvideti način merenja nivoa u preseku uzvodno i neodređenost takvog merenja
- Formirati i krivu protoka za suženje

MERENJE PROTOKA – MERNO SUŽENJE

Kako isprojektovati merno suženje?

- Projektovanje se radi u besplatnom softveru pod nazivom WinFlume - USBR

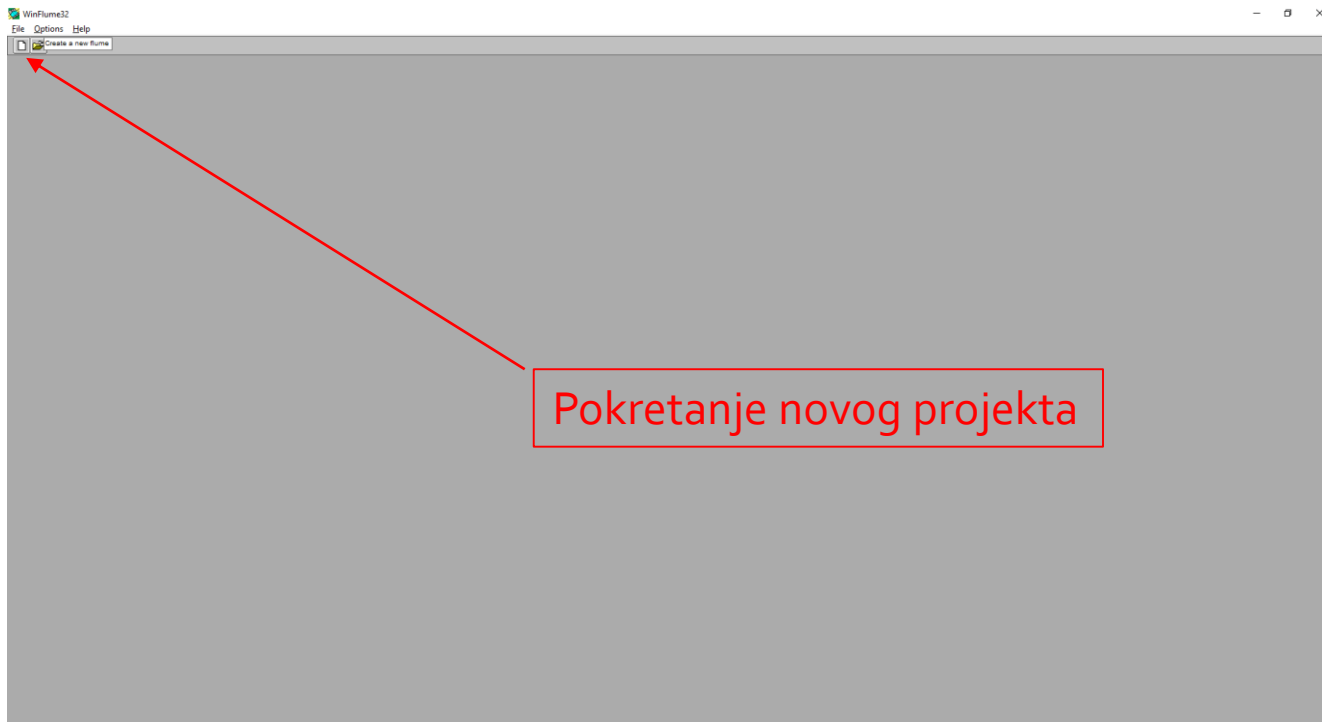


Link za download

<https://www.usbr.gov/tsc/techreferences/computer%20software/software/winflume/32bitwinflumedownload.html>

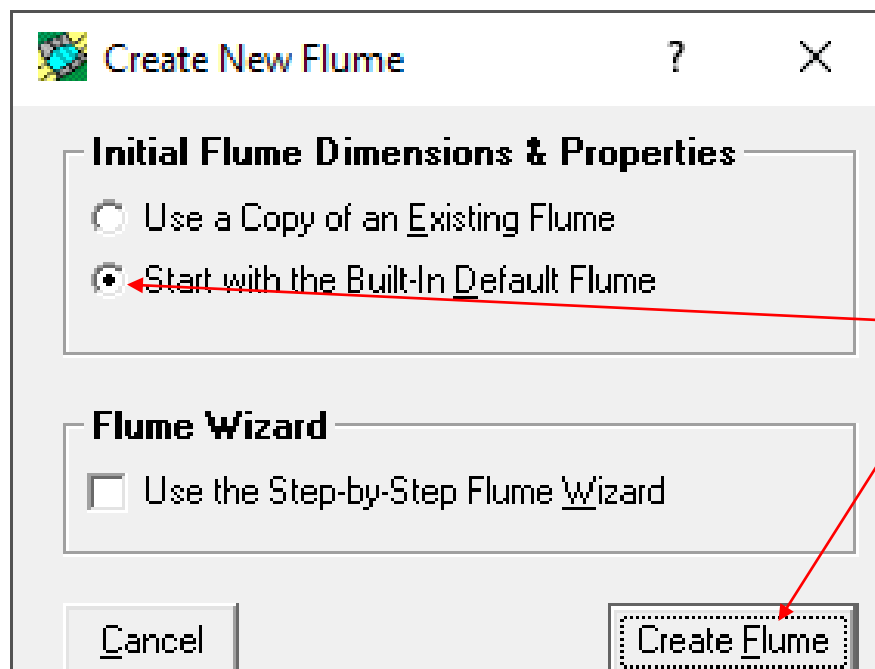
MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Pokretanje programa i podešavanja



MERENJE PROTOKA – MERNOSUŽENJE

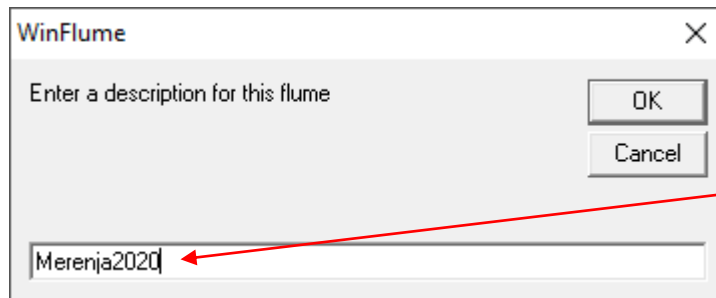
WinFlume – Pokretanje programa i podešavanja



Pokretanje novog projekta od početka

MERENJE PROTOKA – MERNOSUŽENJE

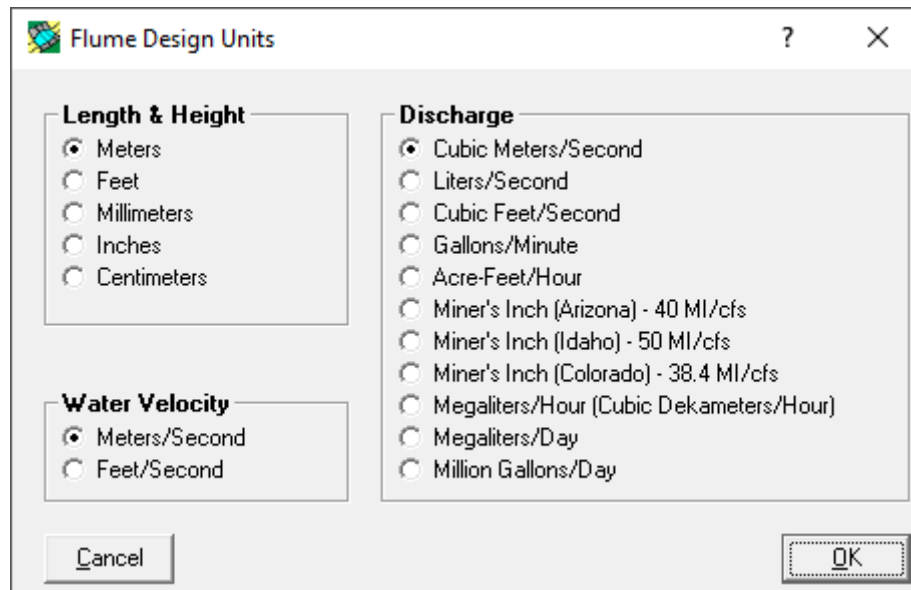
WinFlume – Pokretanje programa i podešavanja



Imenovanje projekta (po izboru)

MERENJE PROTOKA – MERNOSUŽENJE

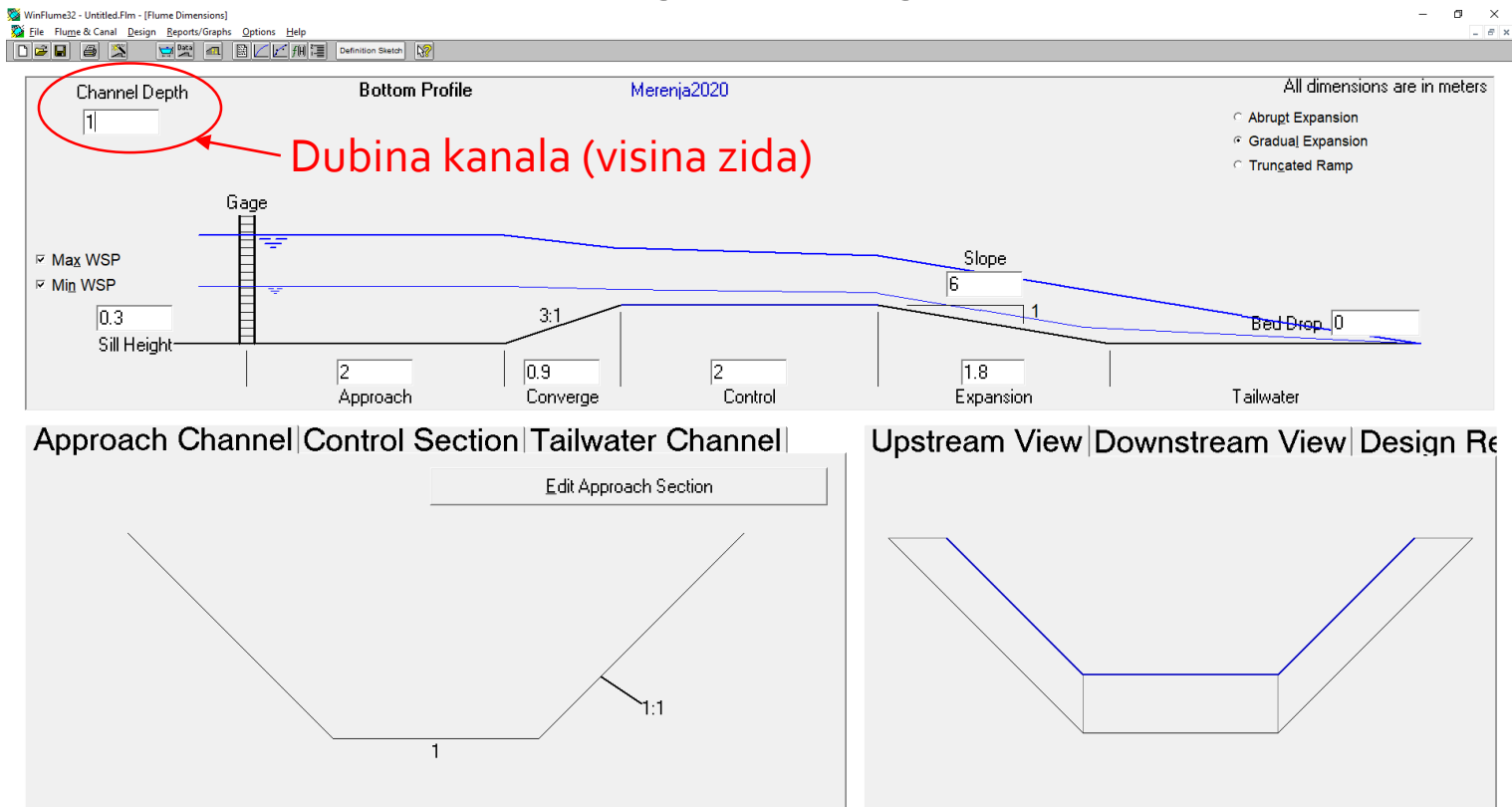
WinFlume – Pokretanje programa i podešavanja



Podešavanje metričkog sistema

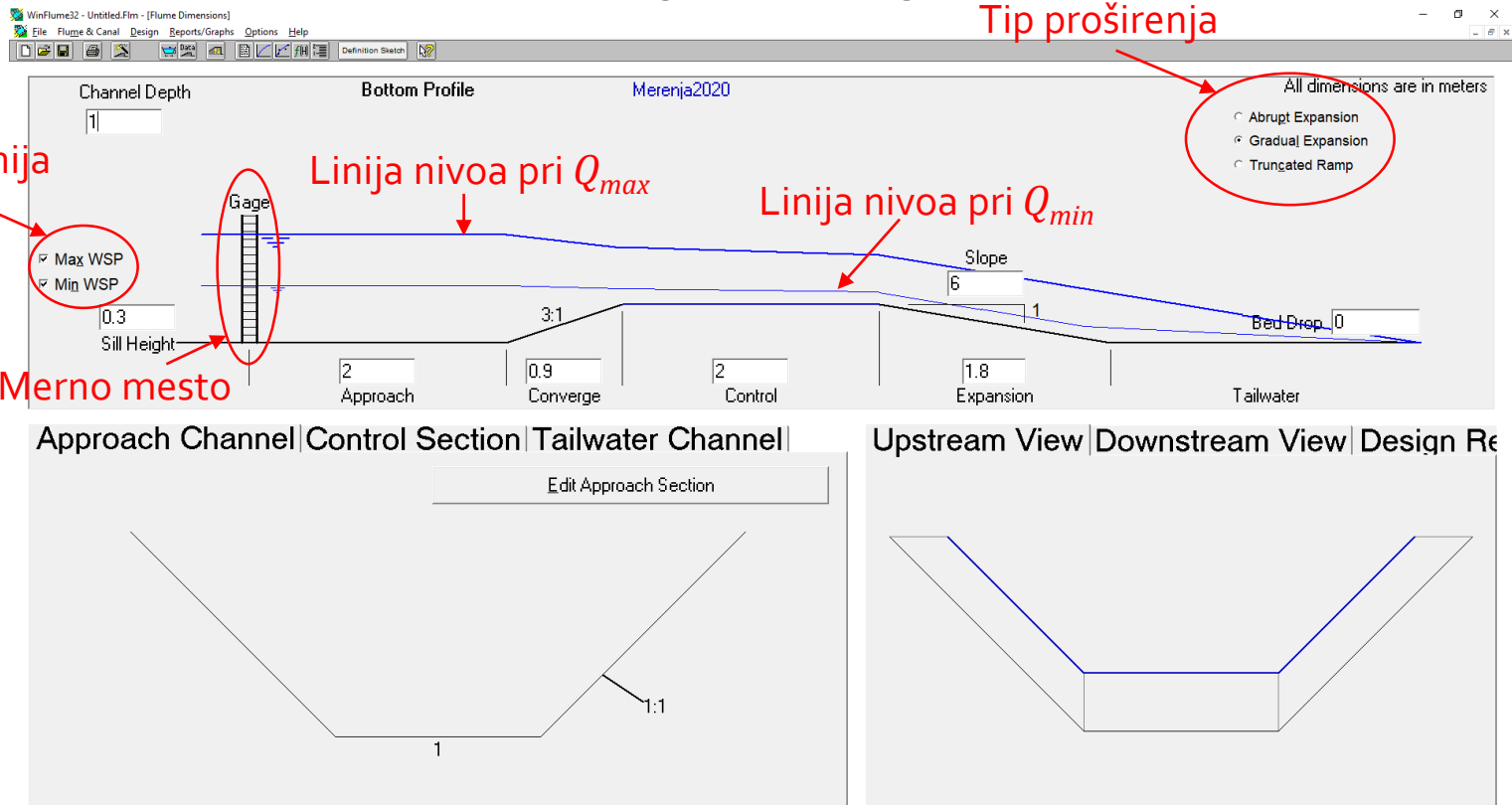
MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Radno okruženje - situacija



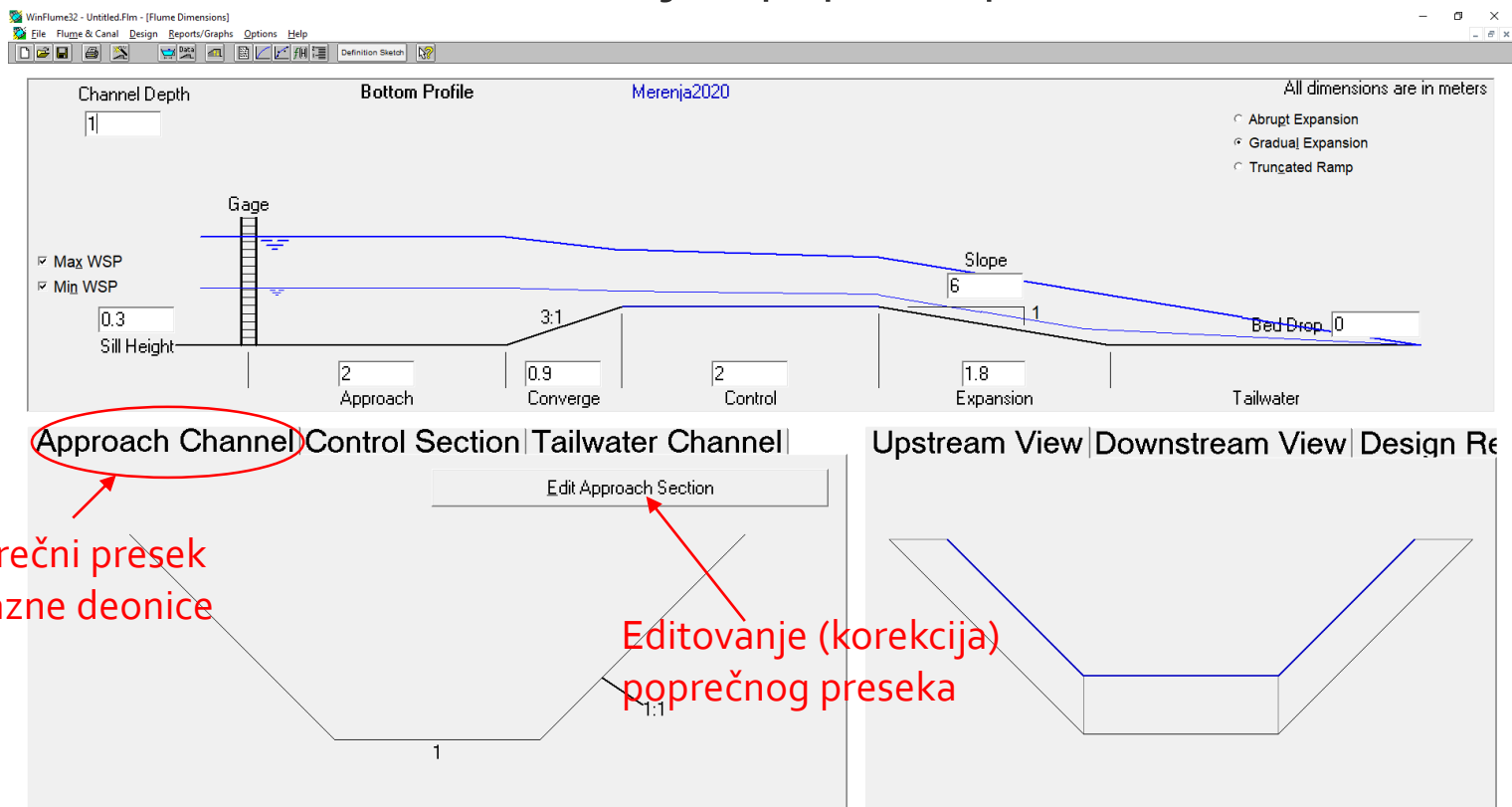
MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Radno okruženje - situacija



MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Radno okruženje – poprečni preseki



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Radno okruženje – poprečni preseki

The screenshot displays the WinFlume software interface for defining a channel profile. The main window is titled "Bottom Profile" and "Merenja2020". It shows a longitudinal view of a channel with various sections: Approach (2m), Converge (0.9m), Control (2m), Expansion (1.8m), and Tailwater. A gage is positioned in the Approach section. The channel depth is set to 1m. The bottom profile is defined by a slope of 6:1 and a bed drop of 0. The water surface profile is shown as a blue line. The interface includes a menu bar (File, Flume & Canal, Design, Reports/Graphs, Options, Help) and a toolbar. A legend in the top right corner indicates the expansion type: Abrupt Expansion, Gradual Expansion, and Truncated Ramp. Below the main profile, there are two cross-section views: "Approach Channel" and "Tailwater Channel". The "Tailwater Channel" section is circled in red. A red arrow points from the text "Poprečni presek nizvodne deonice" to the "Approach Channel" cross-section. Another red arrow points from the text "Editovanje (korekcija) poprečnog preseka" to the "Edit Approach Section" button in the "Tailwater Channel" cross-section. The "Upstream View" and "Downstream View" tabs are also visible.

Channel Depth: 1

Bottom Profile: Merenja2020

All dimensions are in meters

Channel sections: Approach (2), Converge (0.9), Control (2), Expansion (1.8), Tailwater

Parameters: Sill Height (0.3), Max WSP, Min WSP, Slope (6), Bed Drop (0)

Legend: Abrupt Expansion, Gradual Expansion, Truncated Ramp

Cross-sections: Approach Channel, Tailwater Channel

Buttons: Edit Approach Section

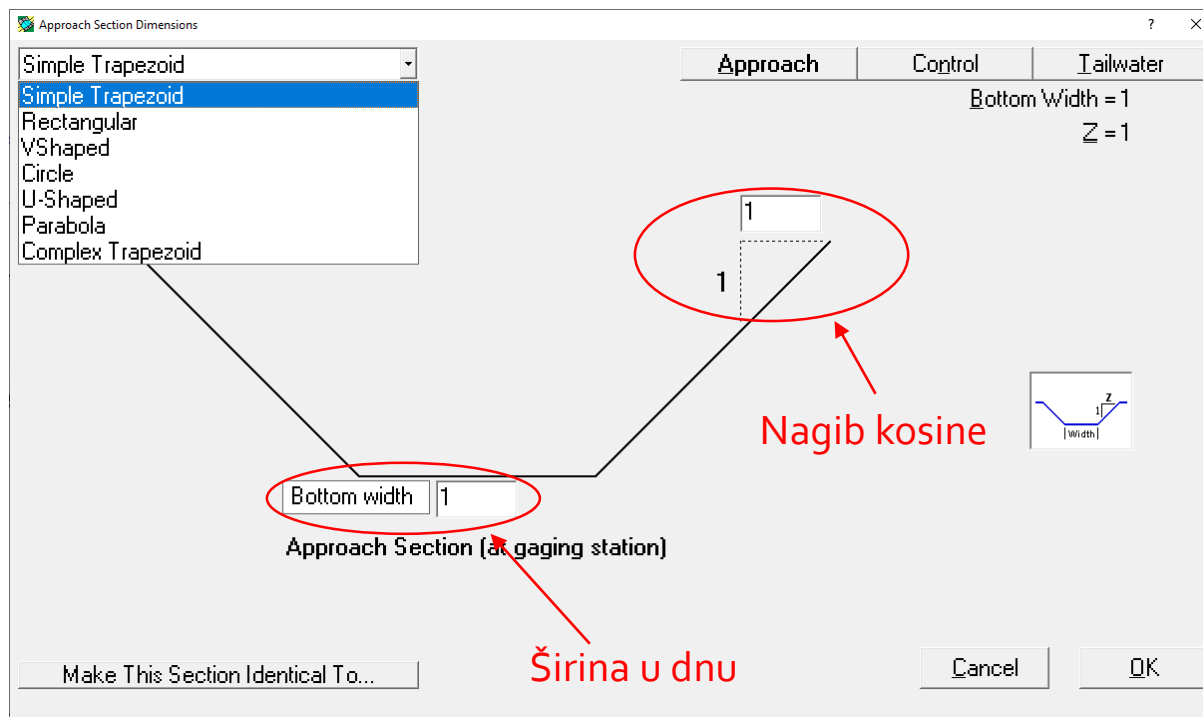
Views: Upstream View, Downstream View, Design Re

Annotations:

- Poprečni presek nizvodne deonice
- Editovanje (korekcija) poprečnog preseka

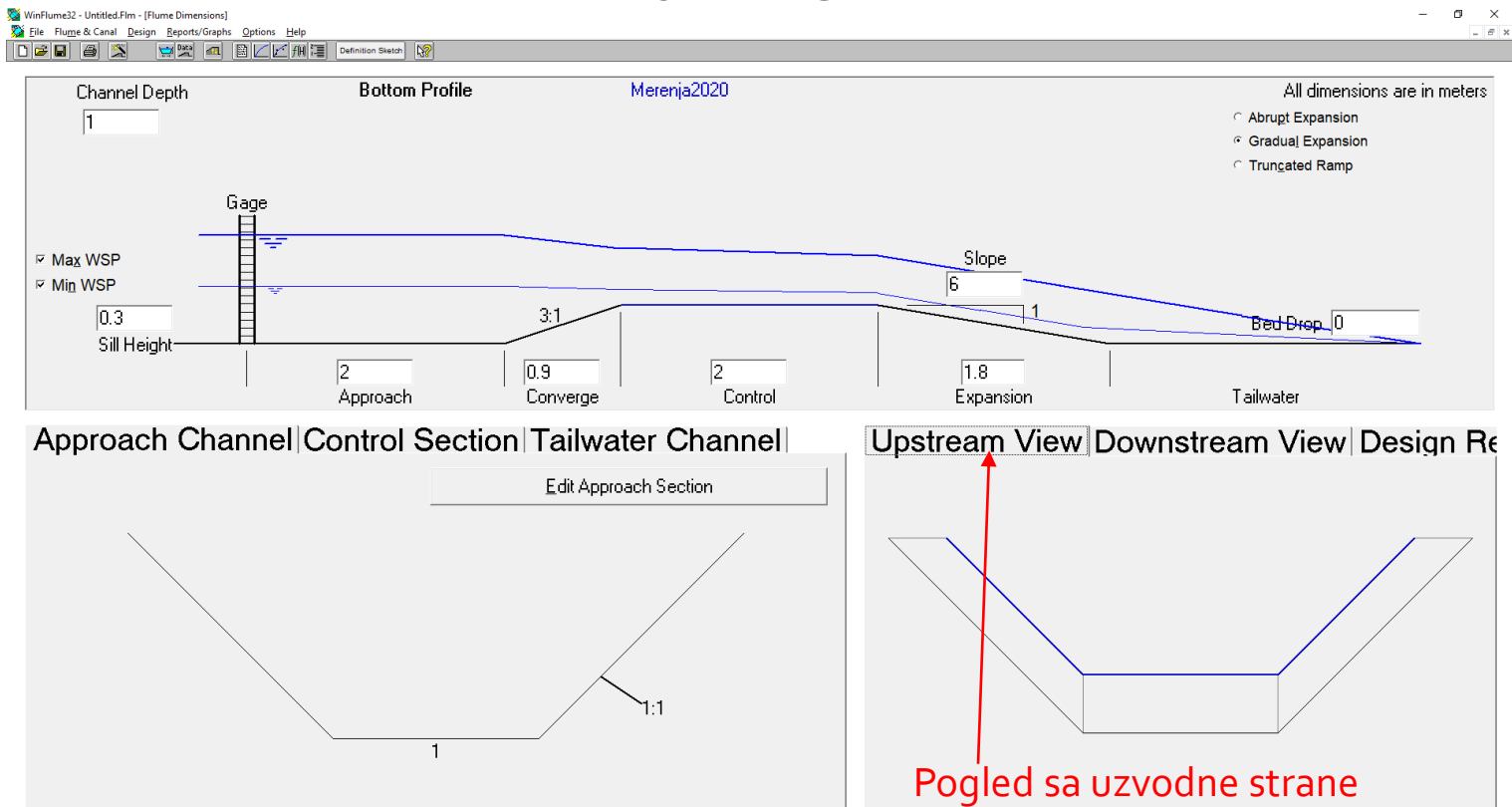
MERENJE PROTOKA – MERNI SUŽENJE

WinFlume – Radno okruženje – poprečni preseki



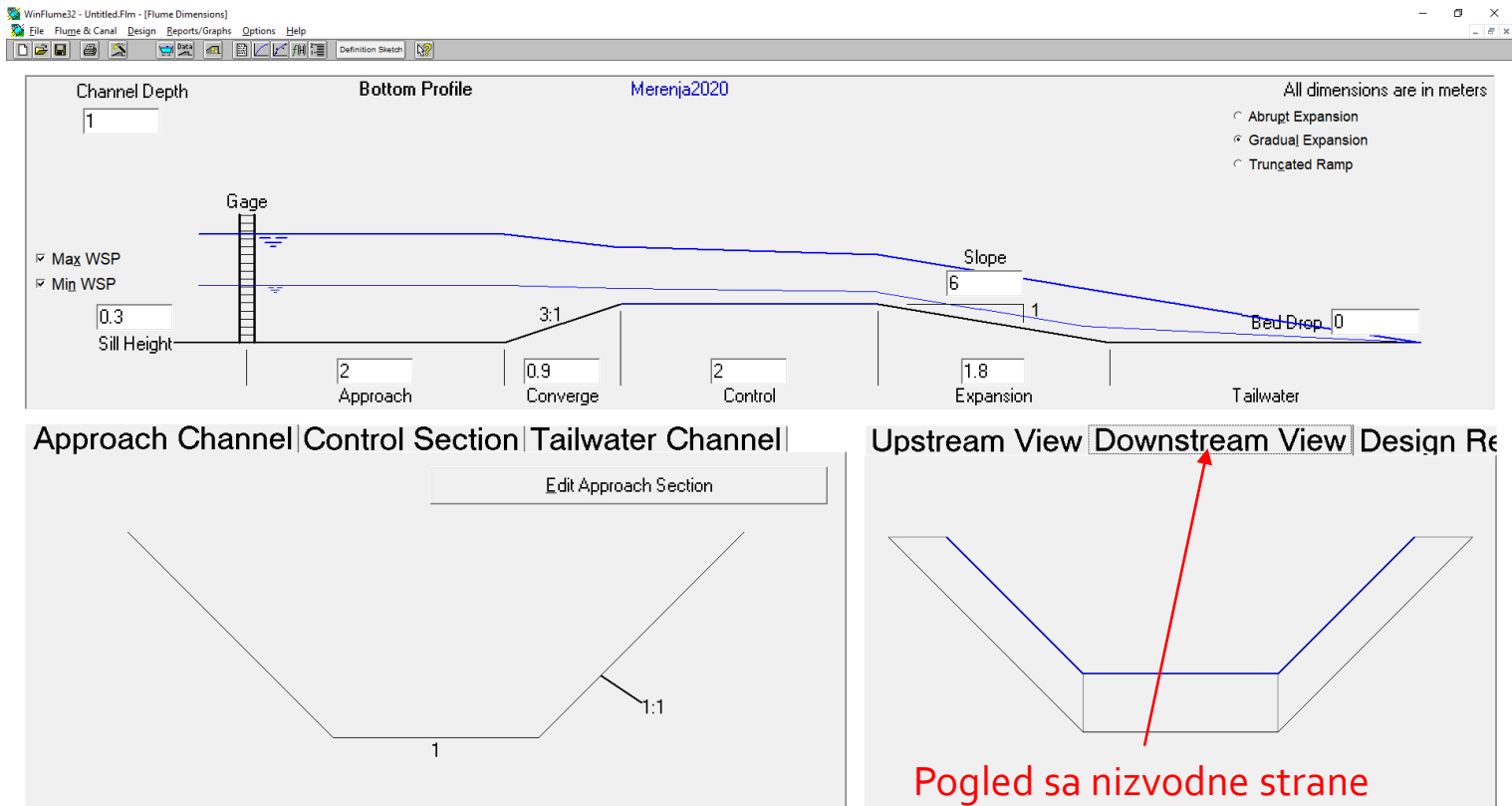
MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Radno okruženje - pogled



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Radno okruženje - pogled



MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Radno okruženje – projektni kriterijumi

The screenshot displays the WinFlume software interface for channel design. The main window shows a 'Bottom Profile' for a channel named 'Merenja2020'. The channel depth is set to 1 meter. The profile is divided into several sections: Approach (2m), Converge (0.9m), Control (2m), Expansion (1.8m), and Tailwater. A gage is located in the approach section. The bottom profile shows a slope of 6:1 and a bed drop of 0. The water surface profile is shown as a blue line above the bottom profile. The software also displays design criteria evaluation results, which are all marked as 'Ok'.

Channel Depth: 1

Bottom Profile: Merenja2020

All dimensions are in meters

- Abrupt Expansion
- Gradual Expansion
- Truncated Ramp

Max WSP
Min WSP

Sill Height: 0.3

Approach: 2

Converge: 0.9

Control: 2

Expansion: 1.8

Tailwater

Slope: 6

Bed Drop: 0

Approach Channel | Control Section | Tailwater Channel

Edit Approach Section

Upstream View | Downstream View | Design Re

Design is acceptable.

$Q_{max} = 1.0000$ cu. m/s
 $Q_{min} = 0.1000$ cu. m/s

EVALUATION OF DESIGN CRITERIA

- Ok. Froude number @ $Q_{max} = 0.285$
- Ok. Freeboard @ $Q_{max} = 0.153$ m
- Ok. Submergence Protection @ $Q_{max} = 0.800$ m
- Ok. Submergence Protection @ $Q_{min} = 0.432$ m
- Ok. Expected uncertainty @ $Q_{max} = \pm 2.51$ %
- Ok. Expected uncertainty @ $Q_{min} = \pm 2.70$ %

Svuda stoji Ok. ako su ispunjeni!!!

Ispunjenost projektnih kriterijuma

MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Radno okruženje – projektni kriterijumi

The screenshot displays the WinFlume software interface for channel design. The main window shows a cross-section of a channel with various sections: Approach (2m), Converge (0.9m), Control (2m), Expansion (1.8m), and Tailwater. A gage is positioned in the Approach section. The channel depth is set to 1 meter. The bottom profile is labeled 'Merenja2020'. The water surface profile is shown as a blue line, and the bed profile is shown as a black line. The slope is 6:1, and the bed drop is 0. The sill height is 0.3 meters. The design criteria are evaluated as follows:

- Channel Depth: 1
- Approach: 2
- Converge: 0.9
- Control: 2
- Expansion: 1.8
- Tailwater: 0
- Sill Height: 0.3
- Slope: 6
- Bed Drop: 0

The design criteria evaluation is shown in the Design Results window:

Design is NOT acceptable, but may be improved.
Type CTRL+D for detailed design review

Qmax = 1.0000 cu. m/s
Qmin = 0.1000 cu. m/s

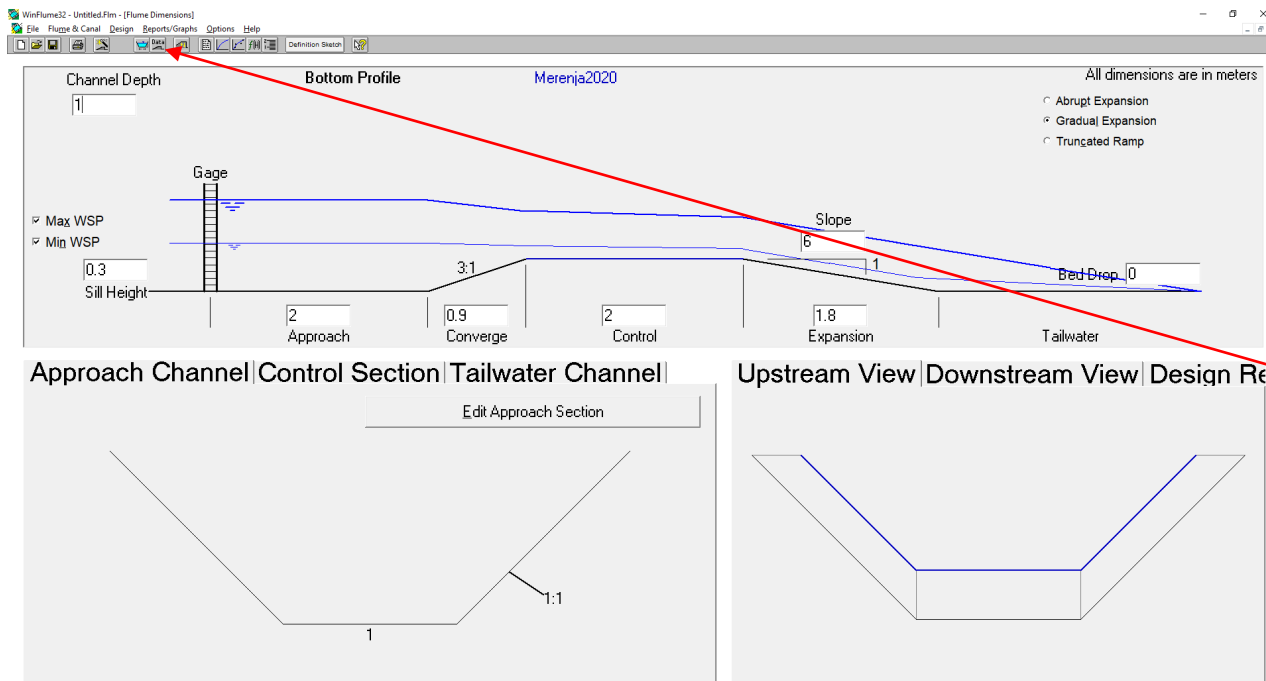
EVALUATION OF DESIGN CRITERIA

- Ok: Froude number @ Qmax = 0.208
- Ok: Freeboard @ Qmax = 0.153 m
- Ok: Submergence Protection @ Qmax = 0.107 m
- Ok: Submergence Protection @ Qmin = 0.231 m
- Ok: Expected uncertainty @ Qmax = ±1.93 %
- Not Ok: Expected uncertainty @ Qmin = ±2.19 %

Red arrows point to the 'Design Results' window and the 'Edit Approach Section' window. The text 'Stoji Not Ok. kod onog koji nije ispunjen!!!' is written in red, pointing to the 'Not Ok' status. The text 'Ispunjenost projektnih kriterijuma' is written in red at the bottom right.

MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Unos podataka za projektovanje



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Unos podataka za projektovanje – tip podloge

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision: 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Stationary Crest ← **Nepokretno dno**

Movable Crest

Flume Construction Material: Concrete - smooth

Roughness Height: 0.00015 meters

Tip podloge – Izabrati gladak beton

Procenjena apsolutna hrapavost podloge

Cancel OK

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Unos podataka za projektovanje – tip podloge

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest: Discharge & Tailwater | Head Measurement | Freeboard Requirement

Range of Flume Operation

| | Discharge | Unit | Tailwater Level, y2 | Unit |
|-----------------------------|-----------|---------|---------------------|--------|
| Minimum Flow to be Measured | 0.1 | cu. m/s | 0.190 | meters |
| Maximum Flow to be Measured | 1 | cu. m/s | 0.693 | meters |

Tailwater Calculations

Method: Manning's equation using n and S Explain Methods

Manning's n: 0.02

Bed Slope (Hydraulic Gradient): 0.001 m/m

Click on + symbols to select from a list of Manning's n-values.

- + LINED OR BUILT-UP CHANNELS
- + EXCAVATED OR DREDGED CHANNELS
- + MINOR NATURAL STREAMS, TOP WIDTH AT $Q_{max} < 30$ met
- + CLOSED CONDUITS FLOWING PARTLY FULL, METALLIC
- + CLOSED CONDUITS FLOWING PARTLY FULL, NON-METALL

Cancel OK

Min i Max protok

Dubine nizvodno za Q_{min} i Q_{max}



Dobijaju se na osnovu Šezi-Manigove jednačine

Manningova hrapavost
(uneti kako je u
zadatku)

Nagib kanala - % ili ‰
pretvoriti u decimalni
oblik

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | **Head Measurement** | Freeboard Requirement

Head Measurement Method: Point gage in stilling well Expected Uncertainty: ± 0.0001 meters

Allowable flow measurement uncertainty (95% uncertainty of a single measurement)

| | | | |
|-----------------|---|-----|---|
| At Minimum Flow | ± | 2.5 | % |
| At Maximum Flow | ± | 2.5 | % |

Totalizing or Averaging

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

Merni instrument za merenje dubine h_1

Očekivana apsolutna (statistička) neodređenost merenja izabranim instrumentom

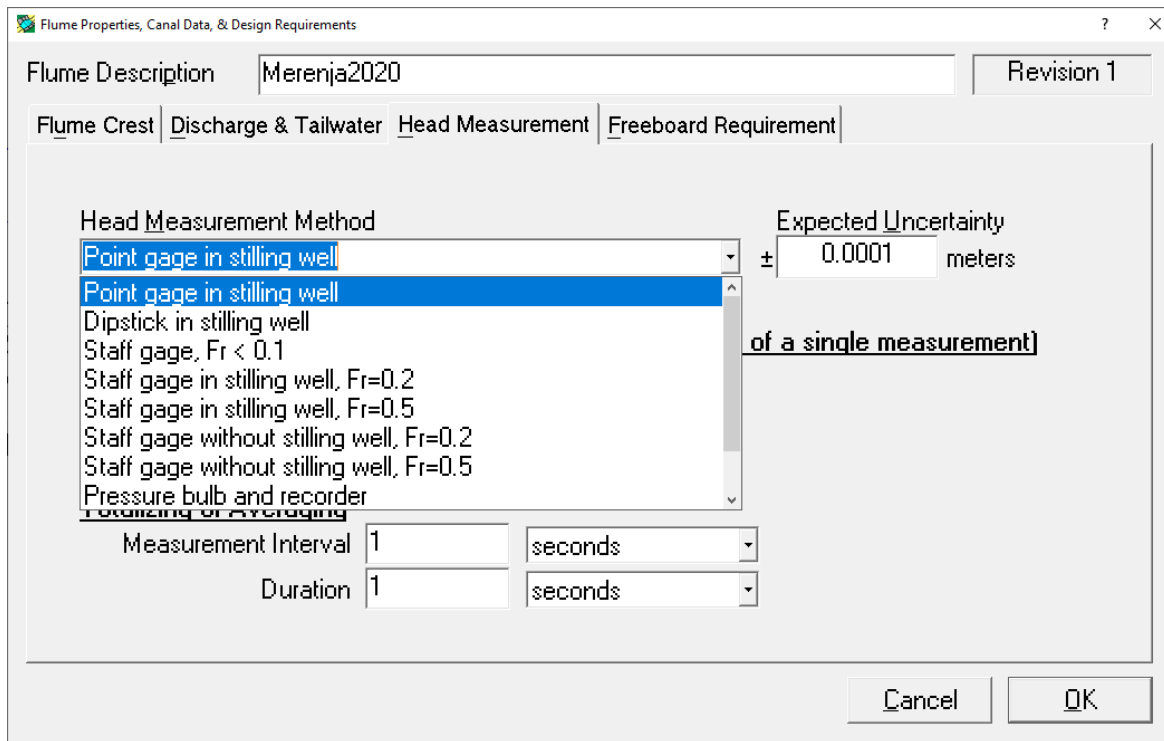
Tražena maksimalna, relativna, neodređenost merenja protoka – zadato u zadatku

Period uzorkovanja nivoa – može da ostane 1s.

Na osnovu izabranog mernog instrumenta, softver metodama propagacije neodređenosti računa neodređenost merenja Q !!!

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa



Merna igla

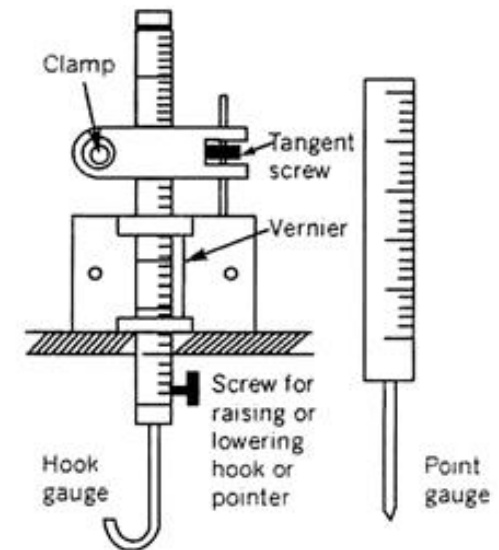
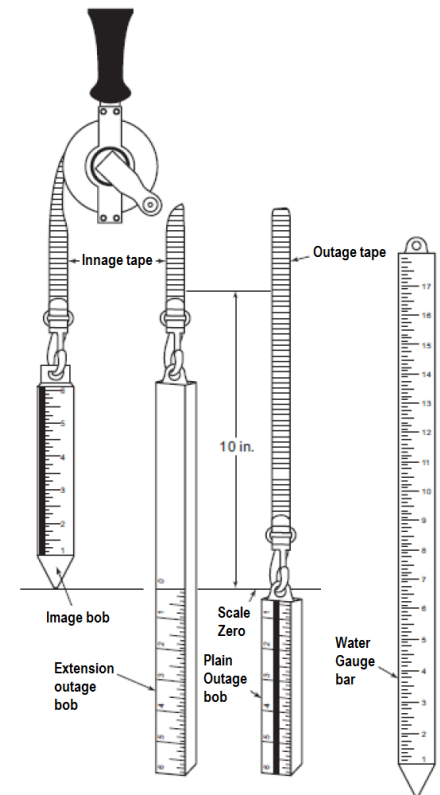
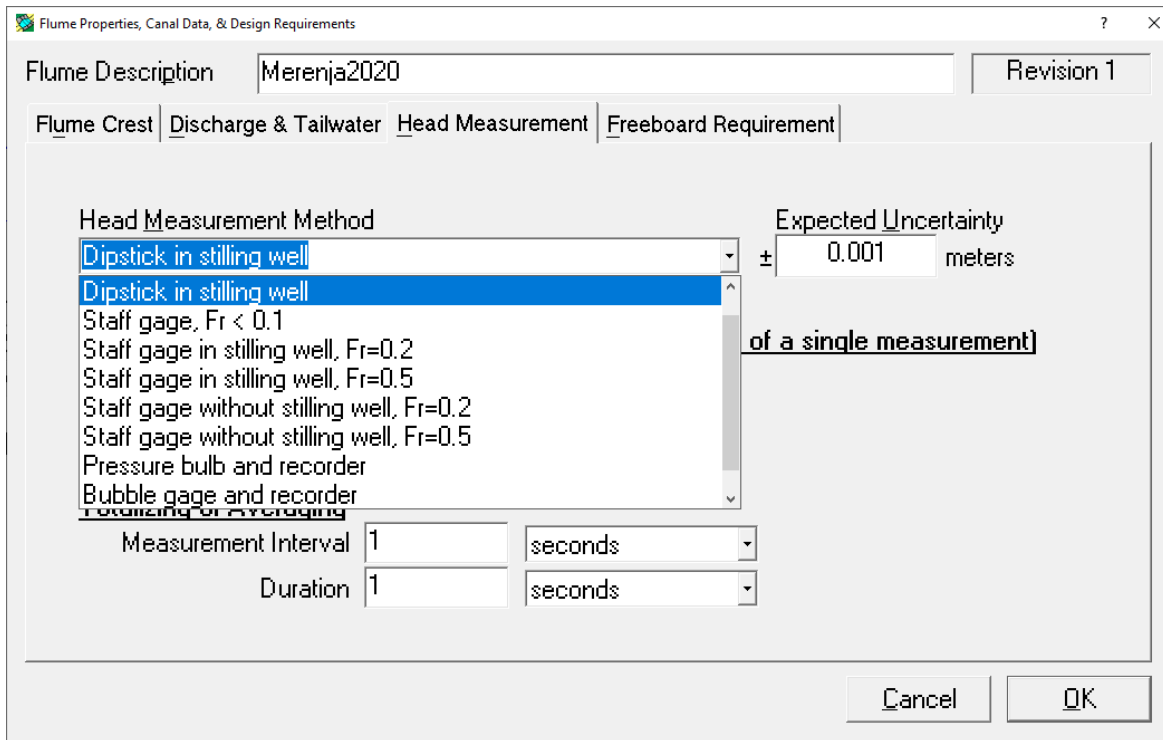


Fig. 15.5. Hook and point gauges.

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Head Measurement Method

Expected Uncertainty: ± 0.004 meters

of a single measurement

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

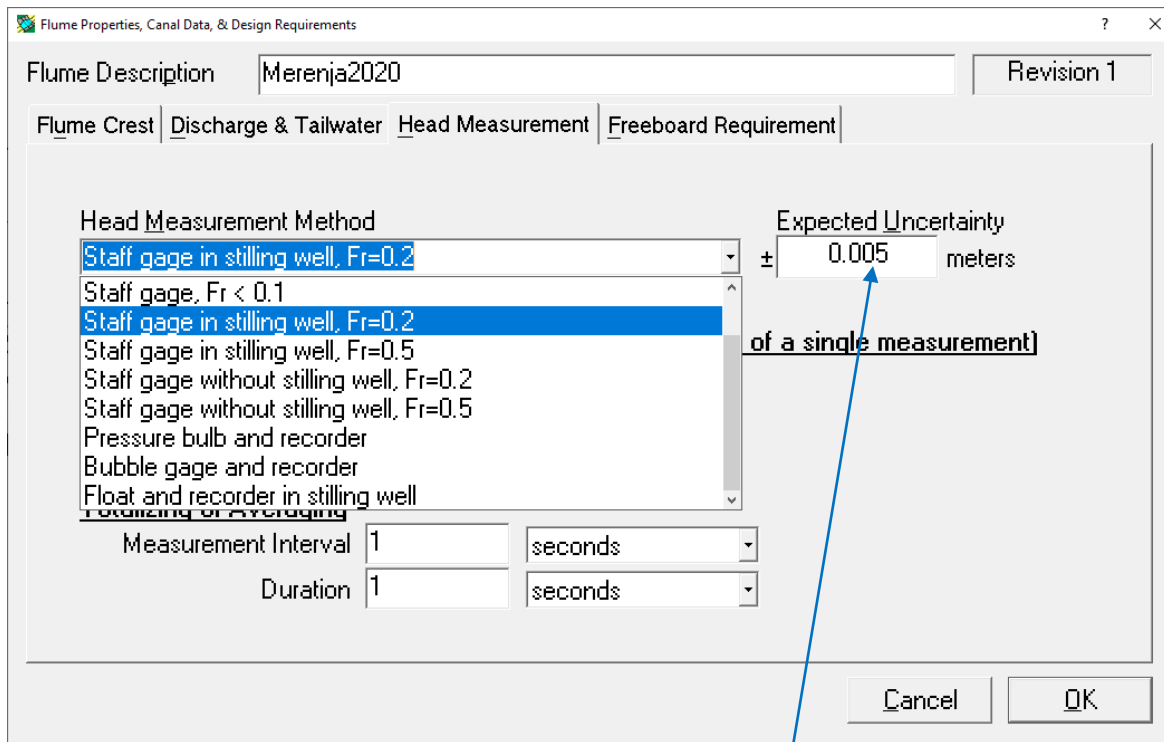
Vodomerna letva
direktno u kanalu - pri
Frudovim brojevima
manjim od 0,1

Očekivana
nedređenost je samo
ako su ispunjeni
hidraulički uslovi (Fr
broj)



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa



Vodomerna letva u umirujućem bunaru - pri Frudovim brojevima oko 0,2



Obratiti pažnju da se sa povećanjem brzine toka (Frudovog broja) povećava očekivana neodređenost merenja nivoa – zbog većih oscilacija nivoa

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Head Measurement Method

| Head Measurement Method | Expected Uncertainty |
|--|----------------------|
| Staff gage in stilling well, Fr=0.5 | ± 0.007 meters |
| Staff gage, Fr < 0.1 | |
| Staff gage in stilling well, Fr=0.2 | |
| Staff gage in stilling well, Fr=0.5 | |
| Staff gage without stilling well, Fr=0.2 | |
| Staff gage without stilling well, Fr=0.5 | |
| Pressure bulb and recorder | |
| Bubble gage and recorder | |
| Float and recorder in stilling well | |

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

Vodomerna letva u umirujućem bunaru - pri Frudovim brojevima oko 0,5



Umirivač oscilacija (crevo, cev, ...)

Obratiti pažnju da se sa povećanjem brzine toka (Frudovog broja) povećava očekivana neodređenost merenja nivoa – zbog većih oscilacija nivoa

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Head Measurement Method

Expected Uncertainty: ± 0.007 meters

of a single measurement)

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

Vodomerna letva direktno u kanalu - pri Frudovim brojevima manjim od 0,2

Očekivana neodređenost je samo ako su ispunjeni hidraulički uslovi (Fr broj)



Obratiti pažnju da se sa povećanjem brzine toka (Frudovog broja) povećava očekivana neodređenost merenja nivoa – zbog većih oscilacija nivoa

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Head Measurement Method

Expected Uncertainty: ± 0.015 meters

of a single measurement)

Staff gage without stilling well, Fr=0.5

Staff gage, Fr < 0.1

Staff gage in stilling well, Fr=0.2

Staff gage in stilling well, Fr=0.5

Staff gage without stilling well, Fr=0.2

Staff gage without stilling well, Fr=0.5

Pressure bulb and recorder

Bubble gage and recorder

Float and recorder in stilling well

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

Vodomerna letva
direktno u kanalu - pri
Frudovim brojevima
manjim od 0,5

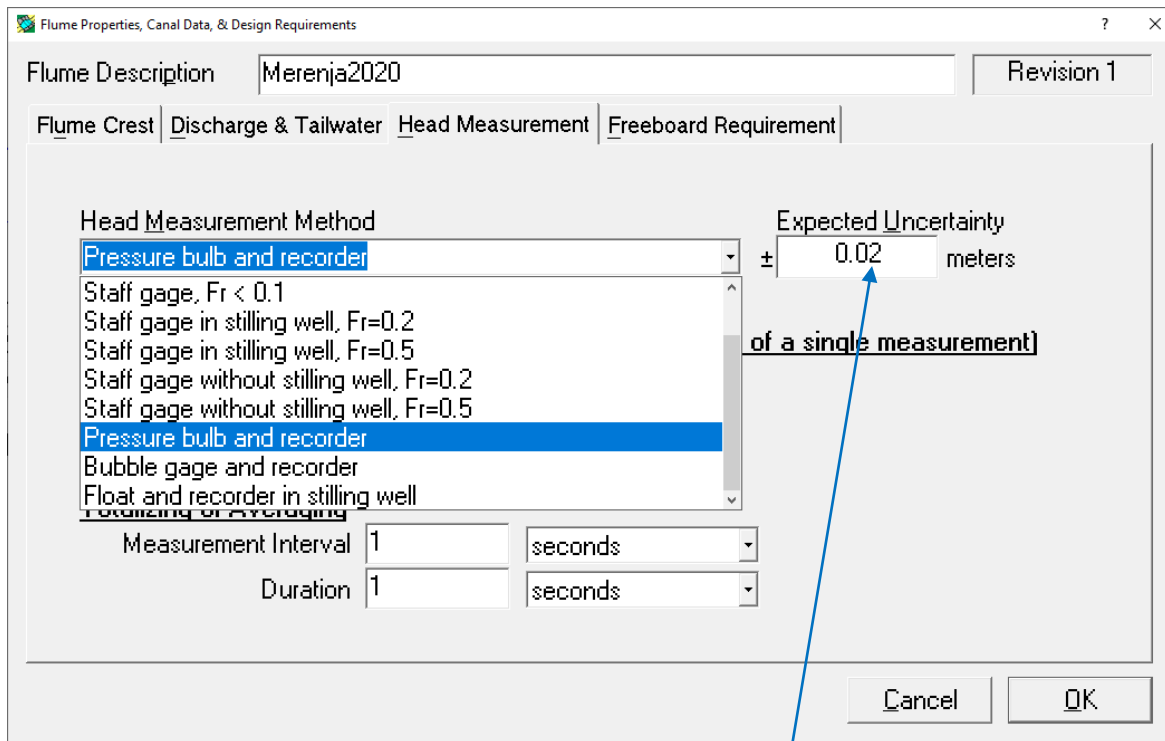
Očekivana
nedređenost je samo
ako su ispunjeni
hidraulički uslovi (Fr
broj)



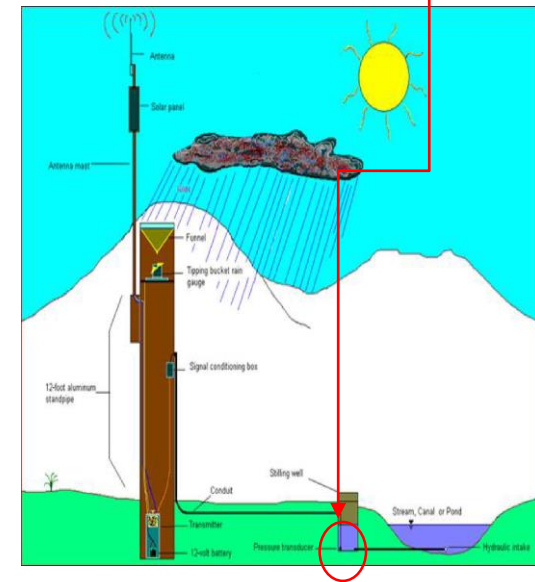
Obratiti pažnju da se sa povećanjem brzine toka (Frudovog broja) povećava očekivana neodređenost merenja nivoa – zbog većih oscilacija nivoa

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa



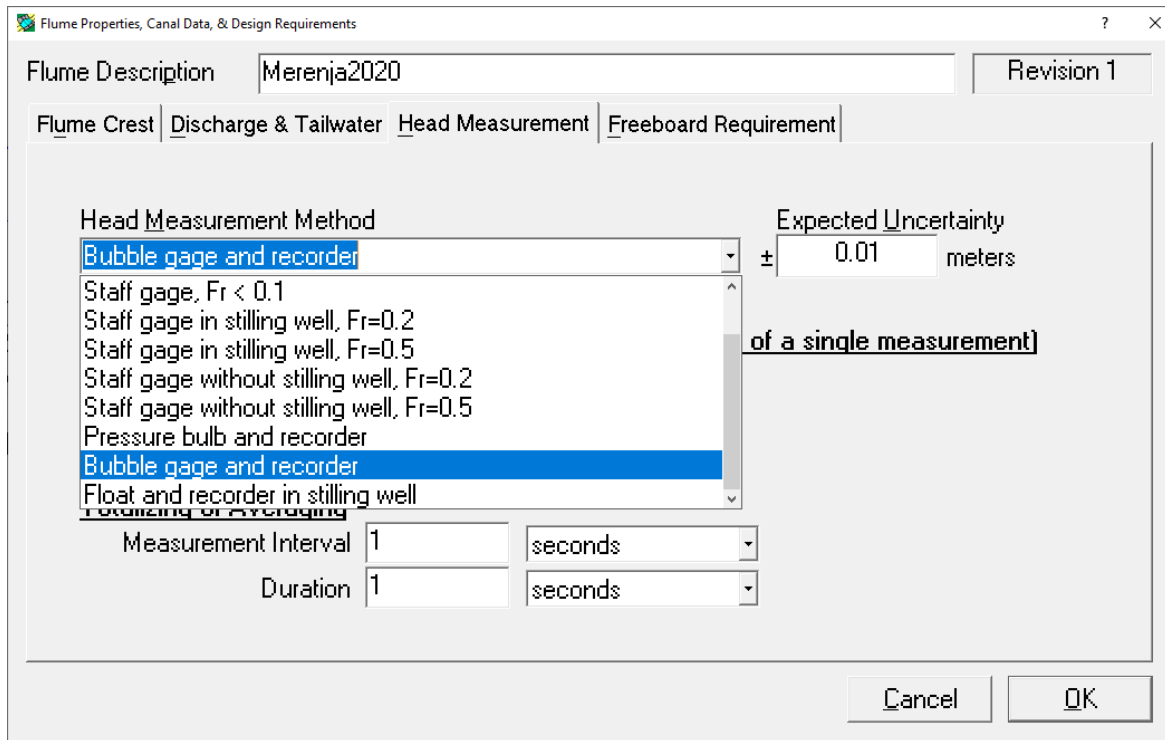
Senzor pritiska na dnu umirujućeg bunara



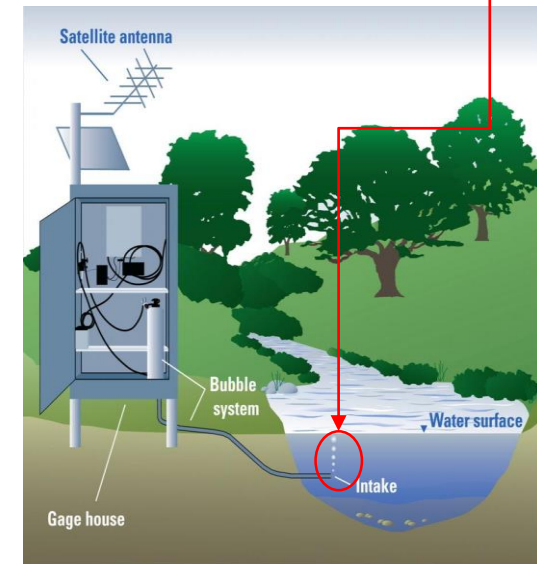
Povećava se neodređenost merenja jer se koristi uređaj sa električnim izlazom koji ima veću neodređenost, ali ima prednost u tome što može da beleži podatke i šalje u bazu

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa



Pneumatska metoda
merenja dubine
Pogledati predavanja



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Izbor načina merenja nivoa

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | Freeboard Requirement

Head Measurement Method: **Float and recorder in stilling well** Expected Uncertainty: ± 0.005 meters

of a single measurement

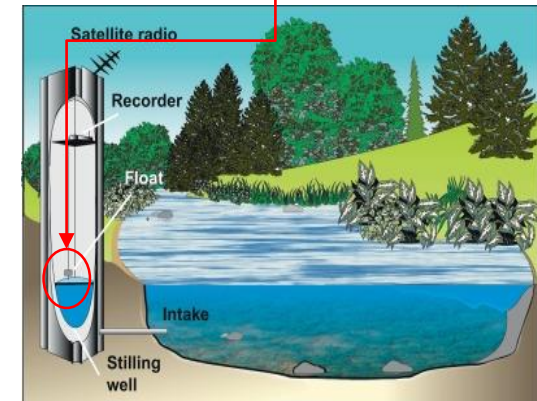
- Staff gage, Fr < 0.1
- Staff gage in stilling well, Fr=0.2
- Staff gage in stilling well, Fr=0.5
- Staff gage without stilling well, Fr=0.2
- Staff gage without stilling well, Fr=0.5
- Pressure bulb and recorder
- Bubble gage and recorder
- Float and recorder in stilling well**

Measurement Interval: 1 seconds

Duration: 1 seconds

Cancel OK

Merenje promene položaja plovku na površini vode



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Zazor (Freeboard)

Flume Properties, Canal Data, & Design Requirements

Flume Description: Merenja2020 Revision 1

Flume Crest | Discharge & Tailwater | Head Measurement | **Freeboard Requirement**

Absolute Distance

Freeboard Requirement is Expressed as an Absolute Distance

Required Minimum Freeboard: 0 meters

Percentage of Upstream Head

Required Freeboard is a Percentage of the Upstream Head, h_1

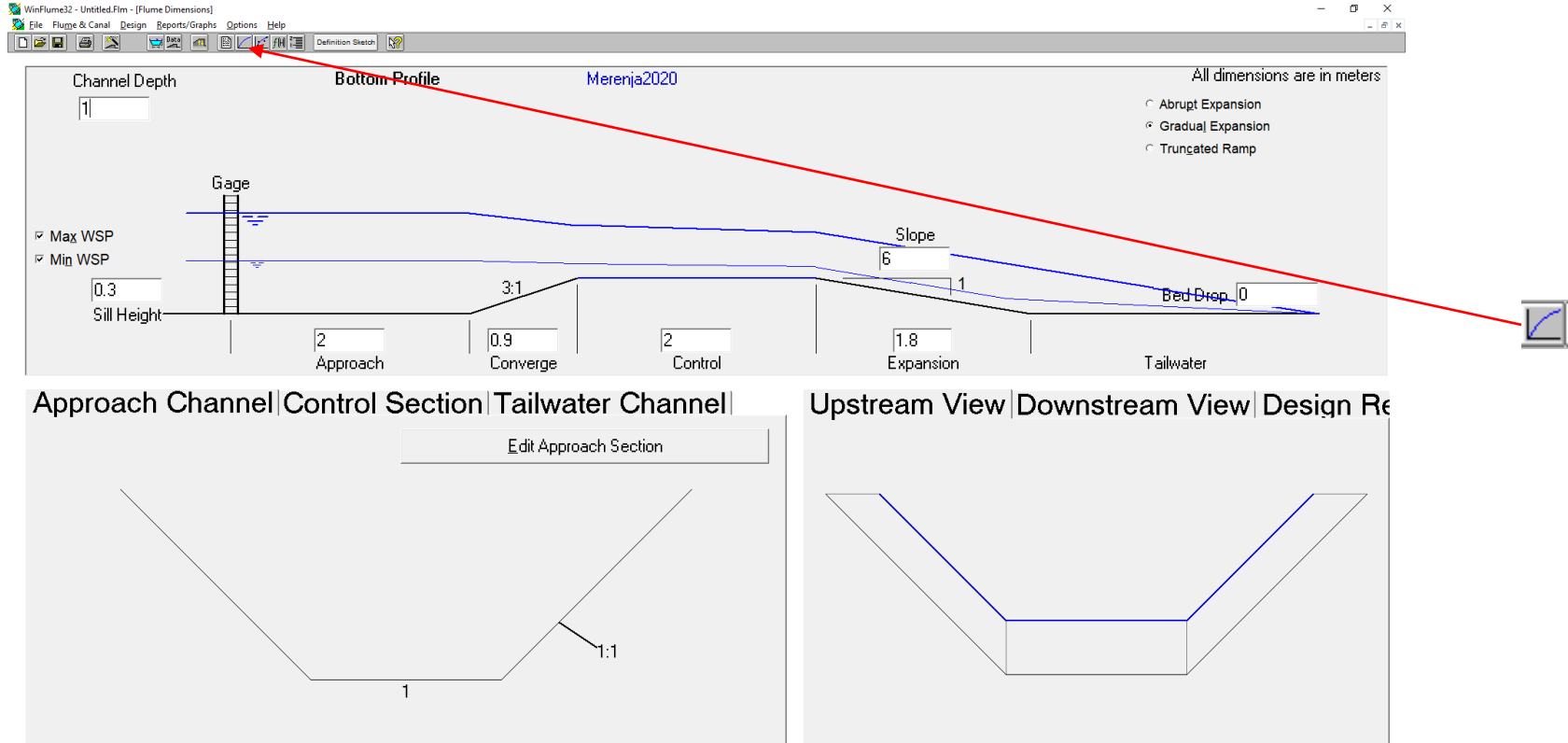
Required Minimum Freeboard: 20 %

Cancel OK

Uslov da visina zida bude za 20% viša od maksimalne kote kako se voda pri max protoku ne bi izlila iz kanala

MERENJE PROTOKA – MERNOSUŽENJE

WinFlume – Kriva protoka za merno mesto



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Kriva protoka za merno mesto

Rating Tables

Table Choices | Rating Table | H-Q Graph | Ditchrider's Table

Table Type

- Head-Discharge (H-Q)
- Discharge-Head (Q-H)

Range
Discharge in cu. m/s.

Minimum

Maximum

Increment

Smart Range

Additional Rating Table Parameters

- Froude Number (Fr)
- Required Head Loss (H1-H2)
- Head-to-Crest Length Ratio (H1/L)
- Upstream Energy Head (H1)
- Upstream Depth (y1)
- Upstream Velocity (Va)
- Discharge Coefficient (Cd)
- Velocity Coefficient (Cv)
- Maximum Allowable Tailwater Head (h2)
- Actual Tailwater Head (h2)
- Actual Tailwater Depth (y2)
- Submergence Ratio (H2/H1)
- Modular Limit

Select All

Clear All

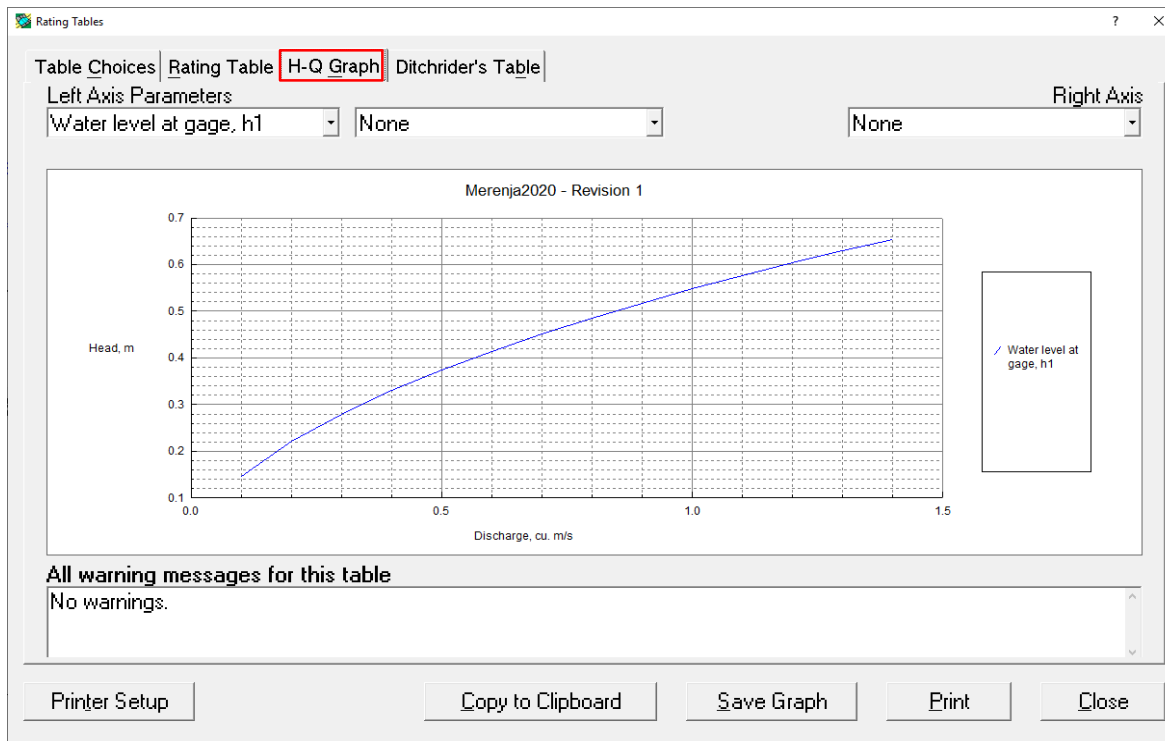
Close

Opseg protoka za koji važi Q-H kriva – uneti svoje podatke

Pored Q-H zavisnosti, na krivoj protoka može da stoji još neka zavisnost

MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Kriva protoka za merno mesto



MERENJE PROTOKA – MERNO SUŽENJE

WinFlume – Zadatak

Podesiti geometriju mernog suženja i izabрати merni uređaj tako da budu ispunjeni uslovi:

- Suženje ne sme da bude šire ni u jednom delu od kanala
- Da se za ceo opseg protoka i nizvodnih dubina u suženju javi kritična dubina, tj. nepotopljeno tečenje
- Izborom mernog uređaja da neodređenost merenja protoka bude manja od 2,5% za ceo opseg protoka
- Da u kanalu na mernom mestu bude zazor od 20% od dubine
- Ako je nemoguće obezbediti nepotopljenost suženja, ukopati nizvodni deo kanala tako da se to postigne

MERENJE PROTOKA – MERNO SUŽENJE

Priložiti

- Poprečne preseke kanala i suženja
- Podužni presek kanala i suženja (situacija)
- Opis mernog uređaja
- Krivu protoka na mernom mestu
- Dokaz ispunjenosti projektnih ograničenja
- Po potrebi „crop-ovati“ slike iz WinFlume-a

MERENJE PROTOKA – VENTURIJEVO SUŽENJE

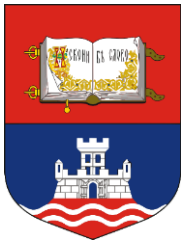
Prednosti mernih suženja za merenj protoka

- Poznata veza između dubine i protoka (lakše meriti nivo)
- Zbog veće brzine u suženju ne može lako da se zapuši
- Stalno merno mesto
- Najpouzdanija praktična metoda određivanja protoka

MERENJE PROTOKA – VENTURIJEVO SUŽENJE

Mane

- Stalno merno mesto
- Zauzima prostor
- Zahteva nepotopljenost suženja (ako se potopi onda moraju da se mere dve dubine umesto jedne)
- Teško je uklopiti u već postojeći sistem (najbolje kad se pravi kad i sistem)



Univerzitet u Beogradu, Građevinski fakultet



Merenje protoka u otvorenim tokovima – Projektovanje mernog suženja



Merenja u hidrotehnici

6. Vežba

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