Fecal water-quality of streams draining mixed-used agricultural basins in southwestern Puerto Rico

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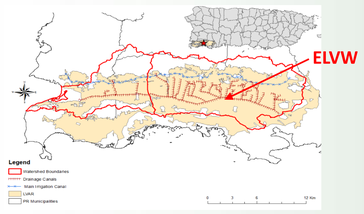
Objectives

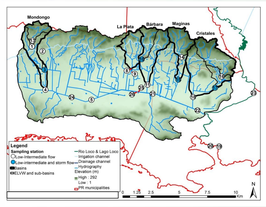
- Characterize contributing (point and non-point) fecal indicators of contamination (FIC) sources to drainage streams
- Identify areas of concern by associating: landuse, FICs, nutrients (nitrogen, phosphorus), suspended sediments, *Bacteroidales* specific markers for humans and cattle
- Link water-quality with land-use

The eastern Lajas Valley watershed (ELVW) in southwestern Puerto Rico



- The ELVW has an area of 14,519 ha, drains north→south and west→east to Guánica Bay (which has important fringing coral reefs)
- Has an irrigation-drainage infrastructure constructed in the 1950s
- Dominating soils are Vertisols with 2 to 4% slopes of agricultural importance

Sampling and sampling stations



- Stations in five basins (Mondongo, La Plata, Bárbara, Maginas, Cristales) within the ELVW
- Sampling points identified, basin boundaries delineated using GIS tools
- Station #2 is a reference station from irrigation channel
- Additional stations were established within targeted areas based on suspected sources of contamination
- Manual sampling conducted from Aug 2014 to Feb 2016
- Synoptic source tracking in July 2017 in Mondongo Basin

Water-quality sampling and analysis

Field

- Stream velocity, pH, specific conductance, temperature, dissolved oxygen using YSI® multi-parameter sonde

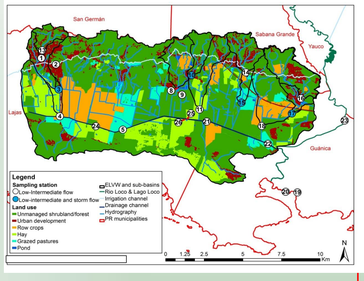
Laboratory

- Total N, dissolved nitrate, total P, dissolved P, heavy metals (US EPA procedures)
- Optical brighteners (Hartel et al 2007), turbidity, suspended sediments
- Enterococci (Enterolert® method)
- *Bacteroidales* human specific marker (HF-183) and *Bacteroidales* bovine specific markers (bacCow gene) determined using modified qPCR (Haugland et al. 2010; Rozier et al. 2015)

Data processing

- Stream velocity converted to discharge and classified into three flow regimes (base-flow, intermediate and high-flow)
- 11 years of data from nearby gaged streams were used with a c/h recession curve and adjusted Riggs (1962) procedure to determine threshold values for baseflow and 7Q2 (which was classified as the maximum flow for intermediate-flow).
- Preliminary draft-man plots looking at multiple correlation among all variables, helped to determine: (i) suitable transformation (i.e. Log10 for FIC and nutrients), and (i) collinearity for multivariate analysis.
- Responses of fecal indicators of contamination to classes of qualitative variables were made using ANOVA.
- Multivariate ordinations (PCA) were done to determine patterns of spatial distribution and to relate water quality parameters with land use.

Land use in ELVW

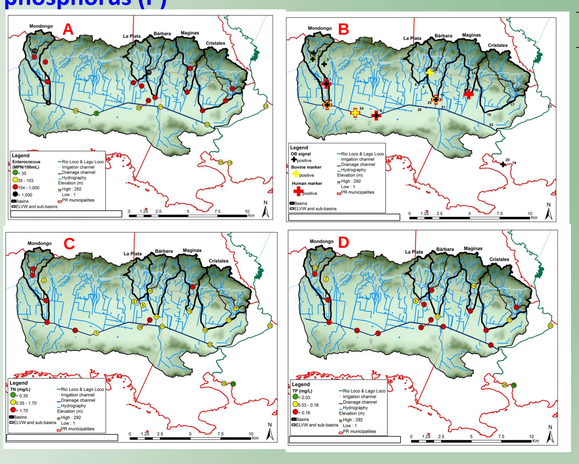


	Basins					
	ELVW [3]	Mondongo	Bárbara	Maginas	Cristales	La Plata
Area (acres)	36,229	3,812	3,786	2,090	4,568	2,822
Population [1]	33,936	7,297	3,403	3,818	5,190	2,759
Number of observed open conduits [2]	157	62	7	0	72	15
	----------% of the total area within each basin----------					
Urban development	9.34	21.08	15.65	30.17	12.85	11.48
Agriculture	29.90	50.24	19.34	21.81	27.75	7.16
• Row crops	10.93	19.08	6.08	2.49	19.92	5.92
• Hay	12.65	30.85	13.06	0.00	3.48	0.00
• Grazed pastures	6.33	0.30	0.20	19.32	4.35	1.24
Unmanaged shrubland/Forest	60.92	28.62	64.87	47.92	59.31	80.29
Pond	0.19	0.07	0.14	0.10	0.09	1.07

1 - USDA-Census (2010); 2 - Open conduits as documented in ground-truthing excursions; 3 - ELVW is the eastern Lajas Valley watershed

- Six land-use land-covers as:
- In urban and suburban areas, potential point-source inputs were waste-water treatment plant (WWTP) discharge points, drinking-water discharge points and potential non-point sources were urban and suburban animals (poultry, wildlife, dogs, cats), and homes/buildings with faulty septic tanks; discharge pipes.
- In rural areas, potential non-point sources were faulty septic tanks, animal feeding operations, large animal production facilities, and grazing animal areas.
- Row crop production limited primarily to rice, and minor extents of cotton and soybean for seed production. Bi-annual rotation of crop-fallow.
- Forage production areas are not fertilized; those that are grazed tend to have higher soil test P levels, due to feces-P recycling

(A) Human bacteroides, cattle bacteroides and optical brighteners (OBs); (B) Fecal enterococci bacteria; (C) Total nitrogen (N); (D) Total phosphorus (P)



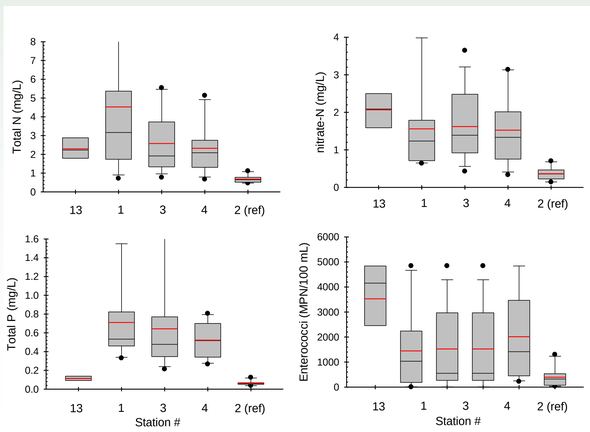
Enterococci concentrations and % positive incidence for bacteroides and optical brighteners (OBs)

		Enterococcus		Positive incidence		
Basin or location	Station	Geometric mean	stderr	Calttle bacteroides	Human Bacteroides	OBs
		--------MPN/100 mL---		----------%----------		
ELVW	All sites	338	131			
Irr. channel	2	241	119	0	0	22
Mondongo	1	442	491	40	20	20
Mondongo	3	522	445	0	40	27
Mondongo	4	1271	532	60	80	27
Mondongo	13	2190	611	50	0	29
Barbara	11	362	482	40	40	18
Barbara	10	1701	511	40	0	10
Maginas	15	329	836	20	40	0
Maginas	14	479	303	0	0	0
Cristales	16	134	212	0	0	0
Cristales	17	153	383	0	25	9.1
Cristales	18	163	624	0	0	0
D.C.	5	32	29	0	75	40
D.C.	21	64	136	0	0	0
D.C.	22	68	223	25	0	0
D.C.	24	102	86	75	50	0
D.C.	25	147	192	0	0	0
Bahía	20	65	52	0	0	67
Bahía	19	77	595	50	50	0
C.F.	9	563	731	0	0	20
C.B.	26	76	44	50	0	0
La Plata	8	955	693	0	0	0
Rio Loco	23	63	316	0	0	0

- The geometric enterococci concentration mean (±1 standard error) across all sites and dates was 338 (131) MPN/100 mL. Only 4.4% of the samples had enterococci concentrations below the suggested EPA threshold of 35 MPN/100 mL
- Overall, the % positive incidence for OBs, cattle bacteroides and human bacteroides was 13, 20, and 22%, respectively.
- Enterococci concentrations decreased with increasing distance from the station downstream of outlet of Mondongo basin (Station #4) through the drainage channel, possibly by solar radiation inactivation or sorption to sediments.
- Reference station #2, located within the irrigation channel that transports water into the Lajas Valley and into Lajas municipality, had mean enterococci concentrations of 241±119 MPN/100 mL. This station tested positive (22%, 2/9) for OBs but not for bovine or human bacteroides marker; suggesting occasional grey-water input along some point within the irrigation channel moving westerly.

Water quality as a result of the WWTP or Lajas City in Mondongo Basin

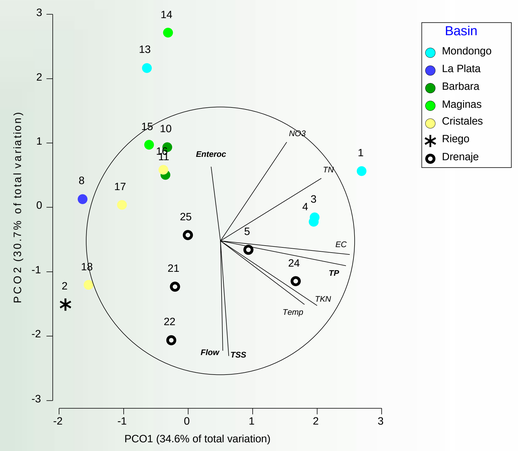
Up- (station #13), down-stream (stations #1, #3, #4) of WWTP, and reference station (#2)



- The station before the WWTP (#13) had significantly highest enterococci concentrations, decreased downstream (stations #1 and #3), and increased again in #4
- The WWTP contributes very little to enterococci concentration, but significantly contributes total P and to a lesser extent total N
- Station #4 was downstream of an un-sewered community of 50-plus household structures, in which we observed at least 16 open pipes that presumably discharged into Mondongo drainage; numerous household animals for local feed and in holding pens

Multivariate results

Multivariate Ordination (Principal Coordinate Analysis, PCO) of centroids of stations across sampling times based on all water quality variables estimated in this study (Euclidean distances). Filled Circles = basins, Empty Circles = Drainage Channel, Asterisk = Reference Station. Vectors represent variables best correlated (> 50%) with the first two axis of the ordination.



- Clear separation among basins based on the measured water quality parameters
- Sampling stations (#1, 3, 4) within Mondongo basin clearly differentiate from the rest, as those stations were plotted on the right of the ordination. Those stations were characterized by having high concentrations of nutrients and elevated EC.
- A conspicuous exemption to this pattern (in Mondongo basin) was that of station 13 (located upstream of the WWTP), which was plotted on the top left section of the ordination. This station, together with station 14 of the Maginas Basin were characterized by having high Enterococci concentrations.
- Most stations of Barbara, La Plata, Cristales and Maginas (excepting 14) had similar water quality parameters, as they all had lower nutrient concentrations.
- Sampling stations located in the drainage channels, were very different from all stations located inside natural basins. These ordination was related with amounts of TSS, which were higher in the drainage channels than anywhere else. Also, flow tended to b higher in drainage channel's stations than the others, especially in stations 21, 22 and 24.

- BEST analyses showed that there was a 45% correlation between water quality parameters and land use variables.
- In particular, the land use variables that best explained patterns of spatial distribution of stations described in the PCO were: % of Urban Development (cover) and % of hailage.

Mean enterococci concentrations among basins

Basin	Enterococci	
	MPN/100 mL	
Barbara	1024	A
Mondongo	736	A
Maginas	318	AB
Cristales	203	B

- The highest enterococci concentrations were observed for those stations draining high-density urban areas such as basins Mondongo (#13 and #4), Bárbara (#10) and La Plata (#8) with geometric mean concentrations of 1,601±438, 1,701±511, 1,271±492 and 956±693 MPN/100 mL, respectively.

Conclusions

- All stations exceeded suggested surface water enterococci EPA threshold of 35 MPN/100 mL (overall mean of 338 MPN/100 mL)
- Enterococci concentrations at the watershed drainage outlet were very low (<100 MPN/100 mL)
- The PR water quality standard and/or suggested levels of enrichment were exceeded in 30%, 43%, and 61% of the sampling stations, for total N, dissolved NO_3-N and total P concentrations, respectively.
- The main sources contributing to enterococci concentrations are point sources within Lajas city and not necessarily the WWTP
- The WWTP within Mondongo basin is an important nutrient (total N and total P) source
- % positive incidence for OBs, cattle bacteroides and human bacteroides was 13, 20, and 22%, respectively

Acknowledgements

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- More information, please visit our website at: http://uprm.edu/waterqualitypr