6TH INTERNATIONAL CONFERENCE ON FLOOD MANAGEMENT
September 2014 - São Paulo - Brazil
ICFM6

THE WARNING FLOOD SYSTEM IN TAQUARI RIVER BASIN

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ABSTRACT: CPRM – Brazilian Geologic Survey is operating a warning flood system in Taquari river basin, located in eastern region of Rio Grande do Sul state in Brazil. This system benefits the population of these cities: Muçum, Encantado, Roca Sales, Arroio do Meio, Lajeado, Estrela, Cruzeiro do Sul Bom Retiro do Sul , Taquari and Venâncio Aires. The basin has 26 thousand Kilometers square, and the river levels and precipitation are monitoring in 27 gauges. These stations belong to CPRM, AHSul, ANA and other agencies. The CPRM stations have automatic equipment, with collection and transmission every 15 minutes via cell phone, which also has conventional equipment with data collection twice daily at 7am and 5pm. This system used the meteorological forecast provided by INPE; CEPTEC and INMET. Hydrological forecasting models used are based on flood propagation and transformation of rain in discharge. The information is disseminated in CPRM website http://sace-taquari.cprm.gov.br/sace-taquari/ and sent to Municipal and State Civil Defense, Cemaden, Cenad and ANA.

Key Words: Warning Flood System, Taquari River Basin

1. INTRODUCTION

CPRM – Brazilian Geologic Survey is operating a warning flood system in Taquari river basin. This system benefits the population of these cities: Muçum, Encantado, Roca Sales, Arroio do Meio, Lajeado, Estrela, Cruzeiro do Sul Bom Retiro do Sul , Taquari and Venâncio Aires. The basin is located in Rio Grande do Sul state in Brazil, in the Guaiba Hydrologic Region and it has 26.415km² of drainage area, inside there are, wholly or partly,119 cities and 1.281.866 inhabitants (Figure 1).

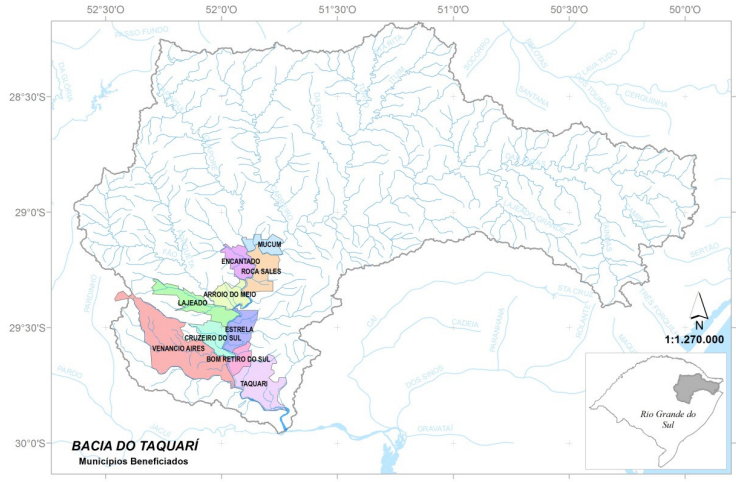


Figure 1: Location figure of Taquari River Basin

Taquari River has springs on Serra Geral, near Aparados da Serra region, on São José dos Ausentes city, in altitudes above 1.100m. The Taquari River is called Antas River until the mouth of Carreiro River. The river has the West direction until Muçum city, where it changes to north/south direction, until its mouth in Jacuí River, near Triunfo city, after the length of 520km. The main tributaries are the rivers: da Prata, Carreiro, Guaporé and Forqueta.

Up to Muçum city, the Taquari River cross very hilly regions, crossing inside deep valleys like canyons, to cross Encostas Superior and Inferior do Nordeste regions. Because of this its Slope is very high, but there are big heels and landings of smaller slopes. This characteristic changes in the beginning of Encosta Inferior do Nordeste to Depressão Central transition, downstream of Muçum city, where the slopes and the side bank are low, what favors the inundation in rainy periods.

The Basin is characterized by torrential regimes of rapid runoff and rapid changes in flows, flash floods, because of high average slope, big density of radial rivers, poor vegetation cover, shallow and low and permeability soils.

According Fundação Estadual de Proteção Ambiental Henrique Luiz Roessler - Fepam (2012),commercial navigation is developed from downstream of Muçum city to the mouth, in an extension of148km, where there are three public ports: Taquari, Mariante and Estrela. The most important port is the Estrela, because of the cargo handled and influence area. The mainly products handled are: grains and bran, fertilizer, coal, vegetable oils, sands and gravel for construction. There is an intensive exchange with Rio Grande port, for the inter region exportation and importation. In the stretch10km downstream of Estrela port, the navigation is guaranteed by BomRetiro do SulDam.

The Taquari river basin presents, according Köeppen climatic classification, two types of climate influenced by morphology: sub-tropical(Cfa) and temperate(Cfb). The subtropical climate occurs in Depressão Central Gaúcha, where the altitudes area low and medium. The Planalto das Araucárias Region belongs to a temperate climate zone, where the altitudes are higher and the average annual temperature ranges from 14,5°C, at headwaters of the basin, to 19°C, at the mouth. The precipitation is uniform distributed during the year, without a dry season. The annual total precipitation ranges from 1700mm at headwaters to 1500mm on the mouth of the basin.

There are several hydro powers in the basin. There are three with power more than 30MW; eleven with power from 1 to 30MW and eleven with power less than 1MW.

ANA and CPRM are responsible for the operation of national basic hydrological network in this basin. But there are gauges from other institutions like Hydropower Companies and Navigation Company.

2. WARNING SYSTEM OPERATION

The warning system operation in Taquari river basin has these activities:

- Monitoring the weather forecast;
- Monitoring and storage of hydrological data;
- Analysis of hydrologic data;
- Preparation of hydrologic forecast;
- Dissemination of information.

2.1 Monitoring the weather forecast

In Brazil the meteorological forecast is taken by INMET and INPE/CPTEC. The Figure 2 shows an example of INPE/CPTEC meteorological forecast.

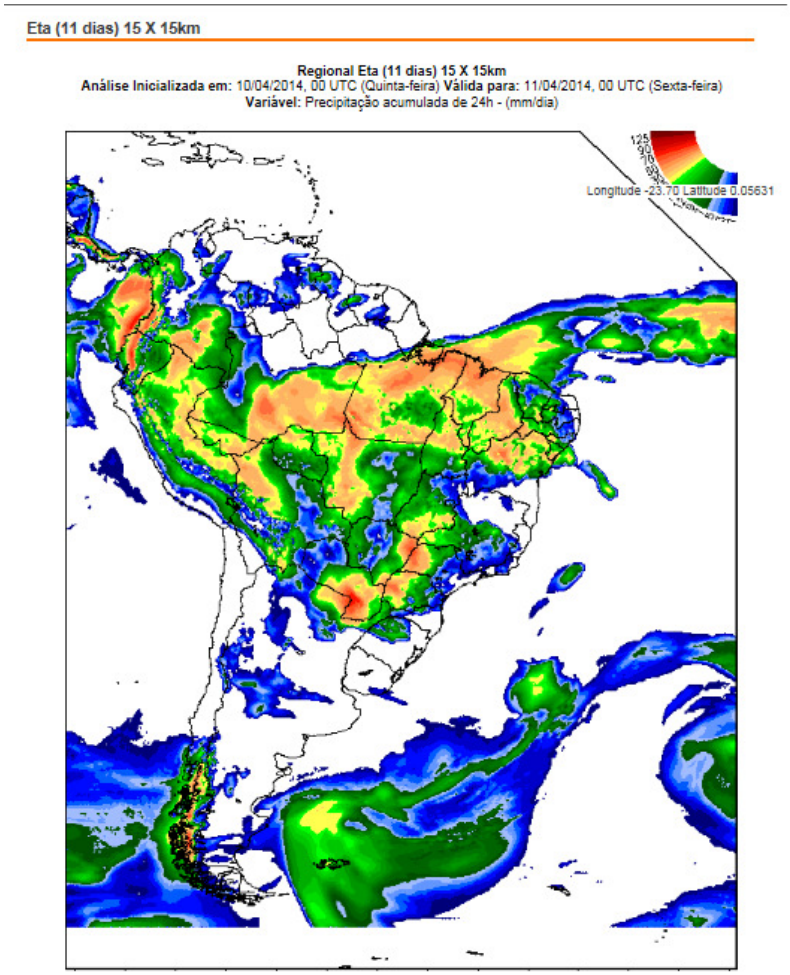


Figure 2: Example of meteorological forecast of INPE/CPTEC

2.2 Monitoring and Storage of Hydrological Data

To operate a warning flood system it is necessary to monitor a hydrological network, especially with automatic equipment with real time data transmission. It is important and desirable gauge redundancy guarantying obtained data especially in warning situations.

INMET and ANA do the hydro meteorological data monitoring in Brazil. The most part of hydrological network operation is done by CPRM. In Taquari river basin, CPRM installed 6 telemetric equipment in the gauges and is going to install more 4 equipment in 2014to operate the warning flood system. And CPRM is identifying other gauges operated by other institutions to use in redundancy of CPRM network.

The Figures 3 and 4 and Tables 1 and 2 show the hydrologic network used in warning flood system operation in Taquari river basin.

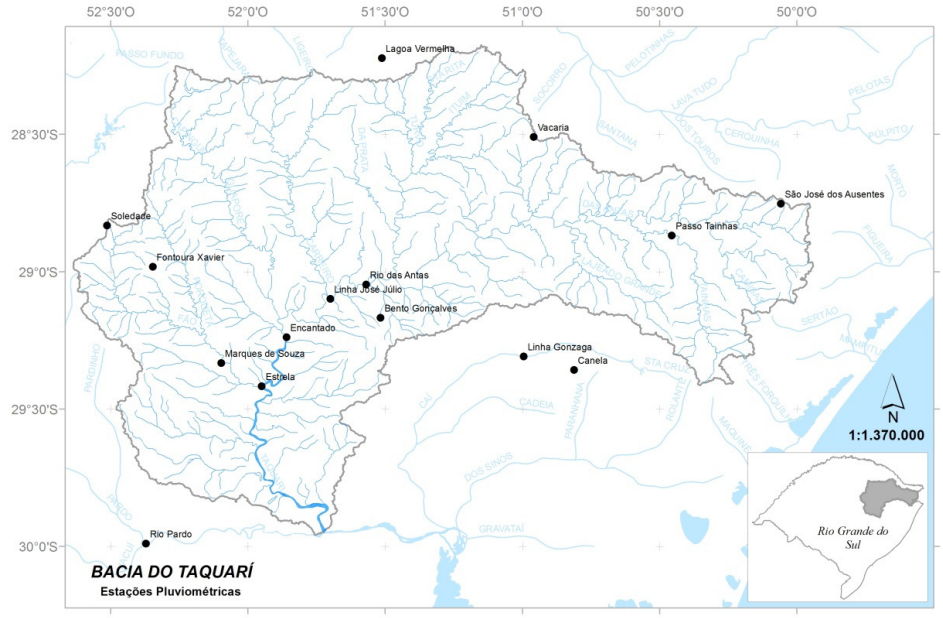


Figure 3: Telemetric Rain Gauges of Taquari River Basin

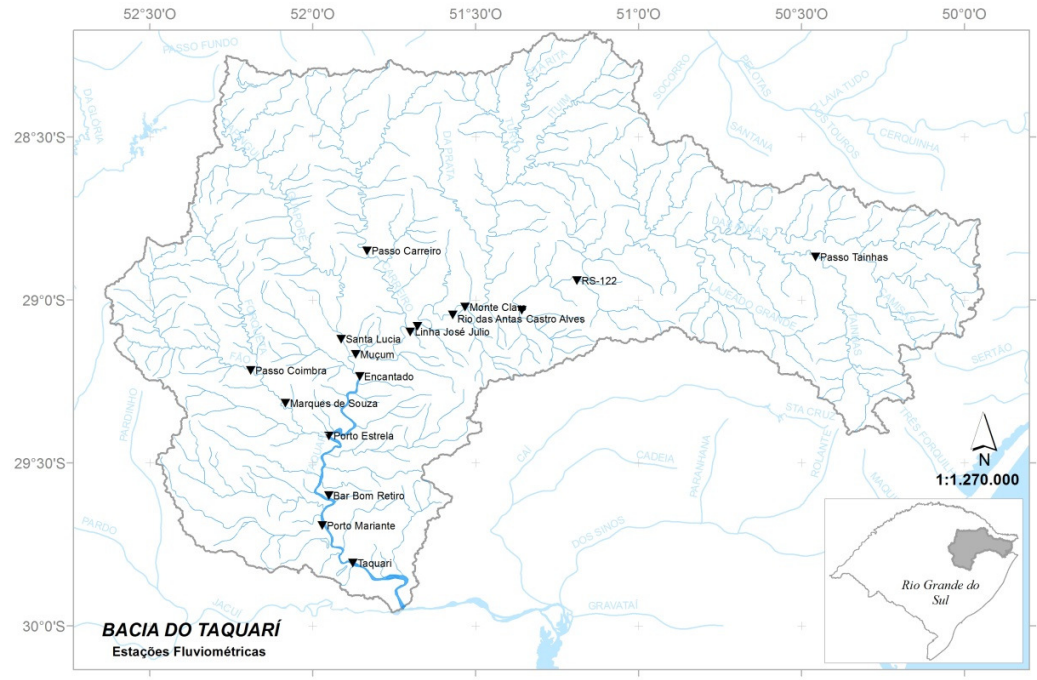


Figure 4: Stream Gauge of Taquari River Basin

Table 1: Rain Gauges of Warning Flood System in Taquari River Basin

Code	Name	Municipality	Latitude	Longitude	Altitude (m)	Paa (mm)	Operation	Type
2951010	Encantado	Encantado	29 14 16	51 51 34	60	1385,3	CPRM	PT
2850009	Passo Tainhas	São Francisco de Paula	28 52 03	50 27 22	640	1546,7	CPRM	PT
2951092	Linha José Júlio	Santa Tereza	29 05 52	51 41 59	-	-	CPRM	PT
s/c	Estrela	Estrela	29 25 00	51 57 00	60	1385,3	CPRM /UNIVATES	PT
02951003/A840	Bento Gonçalves	Bento Gonçalves	29 10 00	51 31 01	624	1579,5	INMET	PT
A879	Canela	Canela	29 21 23	50 48 45	833	1768,4	INMET	PT
s/c	Marques de Souza	Marques de Souza	29 19 54	52 05 52	52	1590	UNIVATES	PT
A829	São José dos Ausentes	São José dos Ausentes	28 45 05	50 03 30	1244	1724,3	INMET	PT
s/c	Rio das Antas	Veranópolis	29 02 44	51 34 11	-	-	UNIVATES	PT
A813	Rio Pardo	Rio Pardo	29 59 19	52 22 18	35	1618,5	INMET	PT
A837	Soledade	Soledade	28 49 52	52 30 49	718	1771	INMET	PT
A880	Vacaria	Vacaria	28 30 30	50 57 32	961	1718,3	INMET	PT
02851014/A844	Lagoa Vermelha	Lagoa Vermelha	28 13 19	51 30 45	842	1769,6	INMET	PT
2950050	Linha Gonzaga	Caxias do Sul	29 18 26	50 59 43	140	1716,8	CPRM	PT
s/c	Fontoura Xavier	Fontoura Xavier	28 58 53	52 20 48	760	1755,1	UNIVATES	PT

Type: P – Rainfall; T - Telemetric; Paa –Average Rainfall; s/c – no code.

Table 2: StreamGauges of Warning Flood System in Taquari River Basin

Code	Name	River	Latitude	Longitude	Flow (m^3/s) (1)	AD (km^2)	Operation	Type
86160000	Passo Tainhas	Rio das Antas	28 52 05	50 27 22	25	1097	CPRM	F T
86298000	RS-122	Rio das Antas	28 56 25	51 11 17	169	7.367	CERAN	F T
86305000	Castro Alves	Rio das Antas	29 01 51	51 21 29	202	8.78	CERAN	F T
86451000	Monte Claro	Rio das Antas	29 01 18	51 31 54	297	12.467	CERAN	F T
s/c	Rio das Antas	Rio das Antas	29 02 44	51 34 11	288	12.298	UNIVATES	F T
86471000	Usina 14 de Julho	Rio das Antas	29 04 49	51 40 40	288	12.931	CERAN	F T
86472000	Linha José Julio	Rio das Antas	29 05 52	51 41 59	298	14000	CPRM	FT
86500000	Passo Carreiro	Rio Carreiro	28 50 56	51 49 57	42	1.829	CPRM	FT
86510000	Muçum	Rio Taquari	29 10 01	51 52 02	364	15.826	CPRM	FT
86580000	Santa Lucia	Rio Guapore	29 07 11	51 54 43	62	2.382	CPRM	FT
86720000	Encantado	Rio Taquari	29 14 04	51 51 18	442	19.2	CPRM	FT
86745000	Passo Coimbra	Rio Forqueta	29 12 58	52 11 23	21	780	CPRM	F
s/c	Marques de Souza	Rio Forqueta	29 19 00	52 05 00	63	2.473	UNIVATES	F T
s/c	Porto Estrela	Rio Taquari	29 25 00	51 57 00	540	23.665	CPRM /AHSul/UNIVATES	FT
86881000	Bar Bom Retiro	Rio Taquari	29 36 00	51 57 00	544	23.85	AHSul	F T
86895000	Porto Mariante	Rio Taquari	29 41 32	51 58 12	552	24.701	CPRM AHSul	FT
86950000	Taquari	Rio Taquari	29 48 25	51 52 34	567	25.913	CPRM AHSul	FT

The data of national basic hydrological network is collected twice a day, at 7 am and 5 pm and are transmitted daily by phone. The telemetric gauges were installed near the conventional ones by CPRM. They have rain and level sensors from Vaissala, the transmission is by GPRS, the frequency of collection and transmission of data is every 15 minutes.

To complete the CPRM telemetric network, gauges of other institutions are used:

- AHSUL which is responsible to managing the navigation Taquari River. The frequency of data collection is hourly and the transmission is made to a ftp area of AHSUL, where the data are available to download;

- The gauges of INMET are telemetric. The data are available to download and data collection frequency is hourly;

- Energy Companies. On Taquari river basin the are several hydropower, some of them have telemetric network, where the stage and discharge data are collect upstream and downstream of dam with hourly frequency.

The monitored data are storage in an information system (SACE – Alert and Fllod Control System) developed by CPRM for this purpose, in Java. This system is able to collect, storage, analyze and disseminate telemetric data collect by different equipment; with transmission by GPRS or satellite, storage in ftp or url.

2.3 Analysis of hydrological data

SACE storage data are analyzed. This preliminary analysis consist in: identify abrupt change in small time slots; long permanence value over a long period; comparison between sensors; comparison the data with a range of maximum and minimum level.

After of preliminary analysis, the rainfall data collected are compared with the weather forecast and the stage and flood monitoring data are compared with warning levels.

It was defined the warning situations. The first one is identifying precipitations that caused inundation in Taquari River Basin. Considering the basin concentration time, weather forecast, lead time prediction and lead time of precipitation anomalies, the accumulated rainfall were studied in 3, 7 and 14 days before the peak of recorded historical flood. For Muçum city 50mm of precipitation in the tributary basin in 3 days and 70mm in 7 and 14 days result in flood with peak stage greater than 1000cm; 90mm in 3 days, 105mm in 7 days and 125mm in 14 days result in flood with peak stage greater than 1500cm.

These are the values of the first warning situation to the weather forecast and rainfall data collect.

The second indicator of warning situation is the monitored stages of the rivers. Three stages were defined: attention, warning and inundation to the Estrela city at the port with the same name. For the other places, the stages were defined preliminary based on Estrela Port, converting the stage in discharge at the port and use the same discharge for the other points converting in stage again, using the stage discharge curves. This definition has to be available with topographic work in each gauge. The Table 3 presents the attention, warning and inundation stages of main points of the warning system. If the warning stage was reached, CPRM advised the Civil Defense of the Cities and emitted informs with the hydrological forecasts.

Table 3: Attention, Warning and Inundation Stages of main monitoring gauges

Gauges	Stages (cm)		
	Attention	Warning	Inundation
Muçum	680	1000	1100
Encantado	560	870	950
Porto Estrela	1360	1700	1800
Bom Retiro	-	1350	1420
Porto Mariante	730	1000	1060
Taquari	680	800	820

2.4 Preparation of hydrological forecast

Flood propagation models were established to forecast the stage of the Taquari Basin rivers. Such models are easier to establish and apply and usually have more satisfactory results than the models of type transformation of rainfall into flow (Tucci, 2005). However, have the disadvantage of small lead time prediction of the order of hours, which may limit its use in some cases. Usually also have good results for basins with drainage areas larger, of the order of 10.000km ² .

The precipitation x discharge models are more complex because that require a larger number of parameters to be calibrated and typically feature are not as efficient for predicting the hydrograph, especially on the rise time and peak. On the other hand, comparing with propagation models, they have the great advantage of having lead time greater than the propagation models, of the order of days. They may also have more satisfactory results for basins with drainage are as smaller , less than 5,000 km ².

The prediction points of Taquari River Basin have the drainage area larger than 15.000km². So first, the propagation models are calibrated and in a second opportunity the precipitation x discharge models will be calibrated.

The prediction models used have a general equation and they are calibrated by multiple regression, deviations and standard errors were analyzed:

$$Qi\ (t+t1) = aQi(t) + bQj(t) + cQk(t) + ...zQn(t) \quad [1]$$

Where:

Qi(t+t1), Qi(t) – flows at the point at the time t+t1 and t

a, b, c...z – coefficients

Qj, k, n (t) - flows at the points j, k, n at the time t

It is possible to storage this kind of low complexity equation on the SACE.

Travel time of flows wave between the monitoring points were calculated, considering the distances between points, the velocity of measured maximum flood and comparison hydrographs. With this information and historical monitoring floods, forecasting models were calibrated. Their resume is presented on Table 4.

Despite the lead time of forecasts between monitoring points be of the order of hours, it's possible to evaluate preliminarily the floods in Taquari, last city benefited of the system, form flows in Muçum, first city, with 30 hours in advance, using the models of intermediary points.

Table 4: Resume of forecast models for each benefited city of the system

City	Model	Lead Time (h)	Data
Muçum	1	6	Flows of Muçum, and Usina 14 de Julho
	2	6	Flows of Muçum, Usina 14 de Julho and Passo Carreio
	3	4	Flows of Muçum, and Linha José Júlio
	4	4	Flowsof Muçum, Linha José Júlio and Passo Carreiro
Encantado	1	-	Flows of Muçum and Santa Lúcia
	2	-	FlowsofMuçum
Porto Estrela	1	6	Flowsof Encantado, Porto Estrela and Passo Coimbra
	2	6	Flows of Encantado, Porto Estrela
Barragem Bom Retiro	1	2	Flows of Porto Estrela
Porto Mariante	1	3	Flows of Barragem Bom Retiro and Porto Mariante
	2	3	Flows of Barragem Bom Retiro
Taquari	1	12	Flows of Taquari and Porto Mariante

2.5 Dissemination of Information

SACE disseminated the monitored data in CPRM website in graphical and tabular form. In warning situation (orange), this system publish and transmit informs in website and by email to the interested public. The Figure 5 shows the page of SACE of Taquari River Basin and Figure 6 presents a model of inform published by the system.

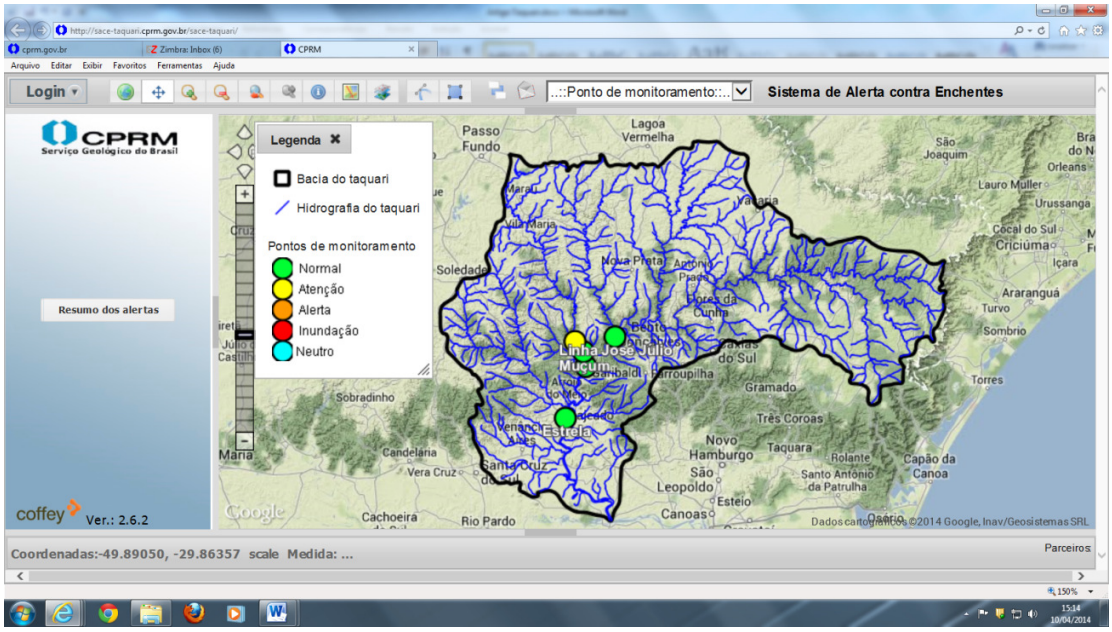


Figure 4: Page SACE Taquari River Basin

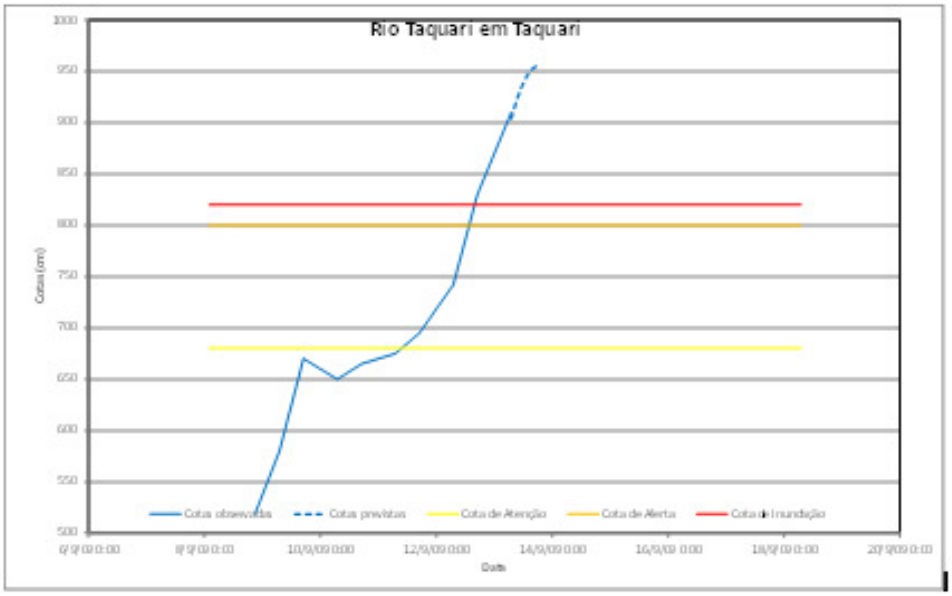
COMPANHIA DE PESQUISA DE RECURSOS MINERAIS - CPRM
DIRETORIA DE HIDROLOGIA E GESTÃO TERRITORIAL - DHT
SURERINTENDÊNCIA REGIONAL DE PORTO ALEGRE - SUREG/PA

BOLETIM EXTRAORDINÁRIO DE MONITORAMENTO DOS DADOS HIDROMETEOROLÓGICOS NA BACIA DO RIO TAQUARI

Porto Alegre, 13 de setembro de 2009.

Prezados Senhores,
Estamos enviando o Boletim Extraordinário do Sistema de Alerta Hidrológico na Bacia do Rio Taquari.
Salientamos que as informações completas estão disponíveis no site: http://sace-taquari.cprm.gov.br/sace-taquari/

Nome da Estação	Curso d'água	Município	Chuva antecedente (mm)				Cota (cm)	Previsão	
			14d	7d	3d	24h	13/09/09 6:00h	Data e hora	Cota (cm)
Muçum	Rio Taquari	Muçum	179,2	161,5	89,2	8,9	1610	13/09/2009 10:00	1550
Encantado	Rio Taquari	Encantado	179,6	155,3	85,3	9,1	1519	13/09/2009 10:00	1410
Porto Estrela	Rio Taquari	Lajeado e Estrela	184,0	148,0	81,9	12,6	2450	13/09/2009 12:00	2432
Barragem Bom Retiro	Rio Taquari	Bom Retiro do Sul	189,5	152,1	83,0	12,8	1855	13/09/2009 08:00	1869
Porto Mariante	Rio Taquari	Venâncio Aires	190,5	152,2	83,1	13,4	1409	13/09/2009 09:00	1422
Taquari	Rio Taquari	Taquari	191,2	150,1	81,8	13,2	904	13/09/2009 18:00	956



Atenciosamente,

Engenheiros Hidrólogos da CPRM
Sistema de Alerta e Controle de Enchentes na Bacia do Rio Taquari – SACE-TAQUARI

CPRM Serviço Geológico do Brasil | Secretaria de Geologia, Mineração e Transformação Mineral | Ministério de Minas e Energia | BRASIL PAÍS RICO É PAÍS SEM POBREZA

Figure 4: Model of Taquari River Basin Inform

3. FINAL CONSIDERATIONS

The installation of telemetric gauges in Taquari River Basin by CPRM was begun on second semester of 2013 and the tests of system operation were begun in 2014.

It is necessary to install the telemetric gauges in Passo Carreiro, Mariante Port, Taquari and Fão River.

It is also necessary to do topographic surveying at benefited cities to define the warning and inundation stages.

Some stage-discharge curves were defined with a small data set and should be validated as new measurements are made.

Some forecasting models have been based on these curves, and thus must also be evaluated over time.

The navigation in the Taquari River is possible because of BomRetiro Dam. It is important to calibrate a hydrodynamic model in the reach between the Estrela Harbor and the dam to improve the hydrologic prediction.

Moreover, it is necessary to calibrate a precipitation x discharge model to increase the prediction time of the basin.

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