A Green Infrastructure for Blue Energy (GIBE) Tool for the Blue Energy Mechanism (BEM) in WaterWorld and associated analyses for Brazil's HEP dams

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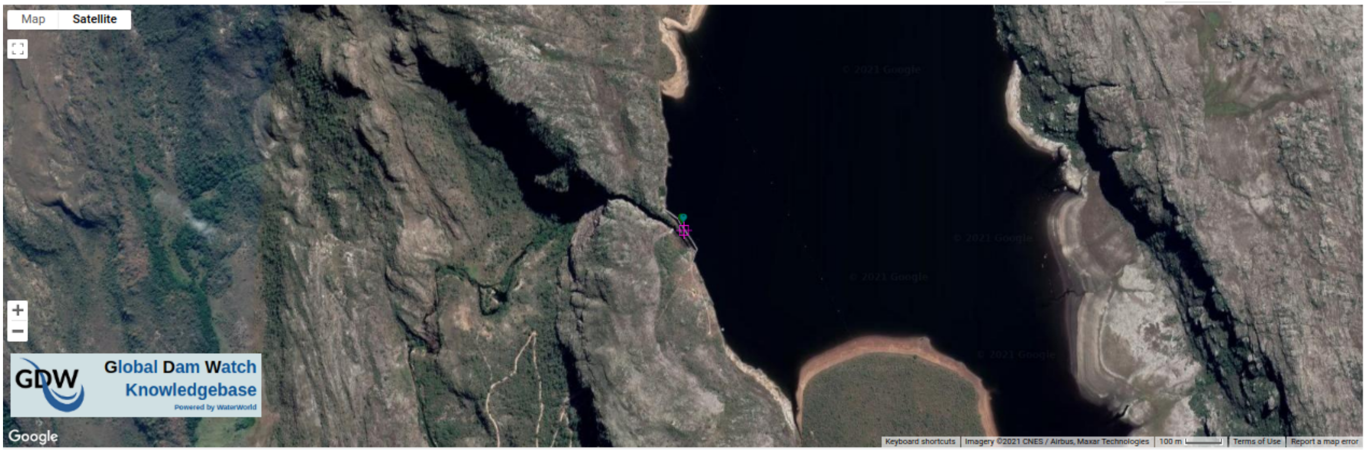
DELIVERABLE 1



Introduction

Convinced of the great potential that ecosystems must improve hydroelectric operations and contribute to energy security, Conservation International (CI) and The Nature Conservancy (TNC) have partnered to create the Blue Energy Mechanism (BEM). The BEM seeks to test the financial viability of an innovative “pay for results” model. In this scheme, the hydroelectric plant pays for the ecosystem services that benefit it once these are specified. The ultimate objective of the BEM is to structure a project in which nature pays for itself and reduces the level of risk for hydroelectric plants. For this, a “project financing” structure is used:

- A specific vehicle is created solely dedicated to supporting the project (SPV).
- Investors finance the ecosystem restoration and / or preservation program in the area of influence of the
- hydroelectric plant. The debt is assumed by the SPV.
- These programs are implemented by local communities and / or specialized companies.
- The services provided by ecosystems are evaluated by an independent third party, and
- Once verified and valued, the hydroelectric plant pays for a portion of the ecosystem services, allowing investors to reimburse and finance project operations.

This report describes a high-resolution analysis of the watersheds of influence for dams in Brazil enabling a ranking of them based on their potential to generate Hydrological Ecosystem Services (HES) within a future financial scheme. The analysis uses the GlobalDamWatch knowledge base (GDWKB) and the WaterWorld Policy Support System. This analysis enables the design of a protocol and tool to assist BEM’s decision-making processes through prioritization of hydropower projects in Brazil. The protocol and tool will be used by managers of the Blue Energy Mechanism to select and engage companies in order to develop a detailed study that potentially evolves into the creation of a payment for results mechanism.

Methods

In line with the proposal supplied by TNC (figure 1) a series of 39 existing **WaterWorld** metrics were brought together and applied to address the requirements of the contract (table 3). These metrics assess the following properties:

- **Current state of green infrastructure.** The current status of hydrologically influential upstream green infrastructure (GI). This metric is intended to define the proportion of the dam watershed under key GI land uses. High values indicate much upstream GI. It is useful in understanding the natural state of the catchment. A compound variable of 3 inputs.
- **Overall contribution of green infrastructure.** The overall contribution of upstream nature to dam operation. This metric is intended to define the influence of upstream green infrastructure on hydrological ecosystem services supplied to the dam. High values indicate GI in areas producing most water or GI hydrologically close to the dam. A compound variable of 5 inputs.
- **Contribution of specific investable natural assets.** The contribution of specific investable natural assets to dam operation. This metric is intended to capture the influence of specific assets that could be better protected or enhanced. It identifies key assets that are influential to the dam. A compound variable of 8 inputs.
- **Risk to green infrastructure contributions.** The current and future risk of upstream land use changes to dam operation. This metric is intended to identify current and future risks associated with land use and land use change that may already or may soon influence the dam negatively, including a specified deforestation scenario. A compound variable of 9 inputs.
- **Benefits of green infrastructure restoration.** The magnitude of beneficial outcomes for the dam of restoration of upstream green infrastructure. This metric is intended to understand the magnitude of

benefits that might accrue to a dam through a specified restoration scenario. A compound variable of 4 inputs.

- **Overall priority for investment.** Combines state, contribution, investment potential, risk and benefits into an overall investment priority

Together these metrics cover all of the factors identified in figure 1 and more. The metrics are now brought together in WaterWorld (www.policysupport.org/waterworld) for ease of application to dam data downloaded from GlobalDamWatchKB (www.policysupport.org/globaldamwatch). Individual maps are written for all of the contributing variables and for the compound indices. All metrics are to the same scale (0-100%) for ease of comparison. In addition maps of the greatest contributing index to each compound index are also written. See table 4 for example maps for the Sao Francisco basin.

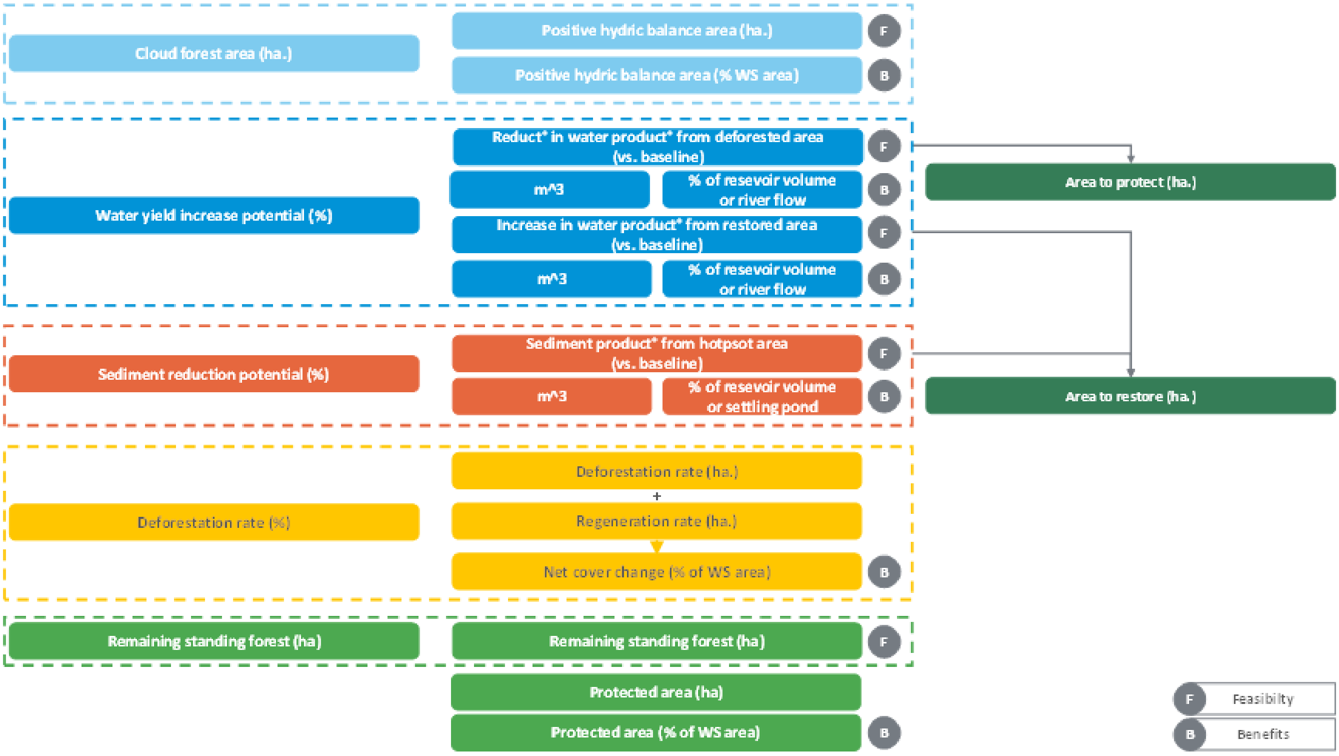


Figure 1 Framework for analysing the the Blue Energy Mechanism (BEM) developed by TNC/CI

The deforestation and reforestation scenarios applied are described below:

Stack 0 | Variable	Value
Form	landuse_change
Action	runmodel_do
Scenario name	defor
Tree:	-100
Herb:	0
Bare:	0
continuing current rate of change according to:	gfc_loss
for (years):	100
multiply current rate by:	1
and add (% forest loss/yr):	0
fraction of forest degradation included:	0
include planned roads (if available):	no
include likely transport routes:	yes
allocate according to agric. suitability:	yes
management effectiveness index for exclusion areas:	1
where	Study area (Hydrosheds)
is	>=
this value:	0
Land converted to	most_common_local
Intensity of use	1
Limit conversion to budget (M USD):	No limit
Mean conversion cost (USD per ha.)	100
Total conversion cost (M USD)	1911.3
Show scenario	Show baseline and scenario

Table 1 Properties of the WaterWorld reforestation/restoration scenario run. In this scenario we remove 100% of tree cover for all pixels in which QUICKLUC allocates deforestation. Deforestation is allocated based on BAU rates from recent (last 20 years) deforestation according to Global Forest Change[1]. Herb and bare cover adjust according to their current ratios. Allocation of new deforestation depends on the observed rates in local administrative areas, is also allocated according to agricultural suitability based on WW input layers and modelled likely new transport routes connecting all urban areas in the region. Deforestation is allowed to occur anywhere at the local rates (i.e. no compensation is set for protected areas. On deforestation, land use is converted to the most common current land use locally (either cropland or pasture). In this way the scenario reflects continued BAU deforestation everywhere, at recent rates measured locally, with conversation to the locally most appropriate land use..

[1] Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. science, 342(6160), pp.850-853.

Stack 0 | Variable	Value
Form	landuse_change
Action	runmodel_do
Scenario name	refor
Tree:	+100
Herb:	0
Bare:	0
continuing current rate of change according to:	gfc_gain
for (years):	100
multiply current rate by:	1
and add (% forest loss/yr):	0
fraction of forest degradation included:	0
include planned roads (if available):	no
include likely transport routes:	yes
allocate according to agric. suitability:	no
management effectiveness index for exclusion areas:	1
where	Study area (Hydrosheds)
is	>=
this value:	0
Land converted to	natural
Intensity of use	1
Limit conversion to budget (M USD):	No limit
Mean conversion cost (USD per ha.)	100
Total conversion cost (M USD)	805.314
Show scenario	Show baseline and scenario

Table 2 Properties of the WaterWorld reforestation/restoration scenario run. In this scenario we add 100% of tree cover for all pixels in which QUICKLUC allocates restoration. restoration is allocated based on BAU rates from recent (last 20 years) tree cover gain according to Global Forest Change[2]. Herb and bare cover adjust according to their current ratios. Allocation of new restoration depends on the observed rates in local administrative areas, and modelled likely new transport routes connecting all urban areas in the region. Restoration is allowed to occur anywhere at the local rates (i.e. no compensation is set for protected areas. On restoration, land use is converted to natural land use. In this way the restoration scenario represents business as usual rates of tree recovery continued forward at the same rates.

Results

According to the GlobalDamWatchKB there are some 8384 dams in Brazil of which 1127 have a reported HEP capacity (those shown in colour in figure 2). The mean HEP capacity is 170 MW with more than 100,000 MW (100 GW) total capacity in the country.

[2] Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. science, 342(6160), pp.850-853.

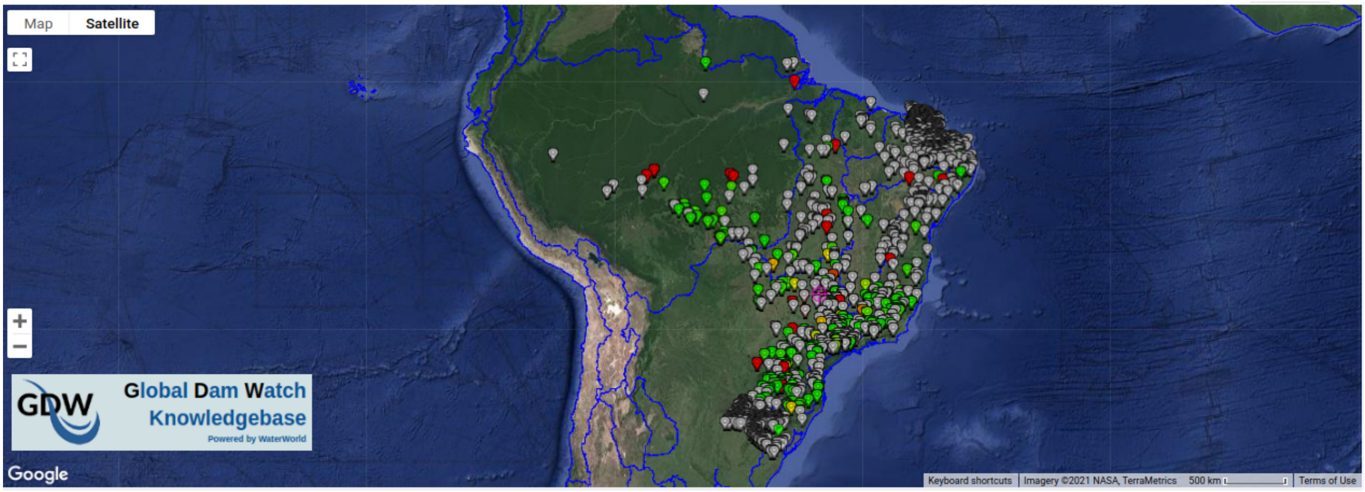


Figure 2 Dams in Brazil from GDWkb www.policysupport.org/globaldamwatch

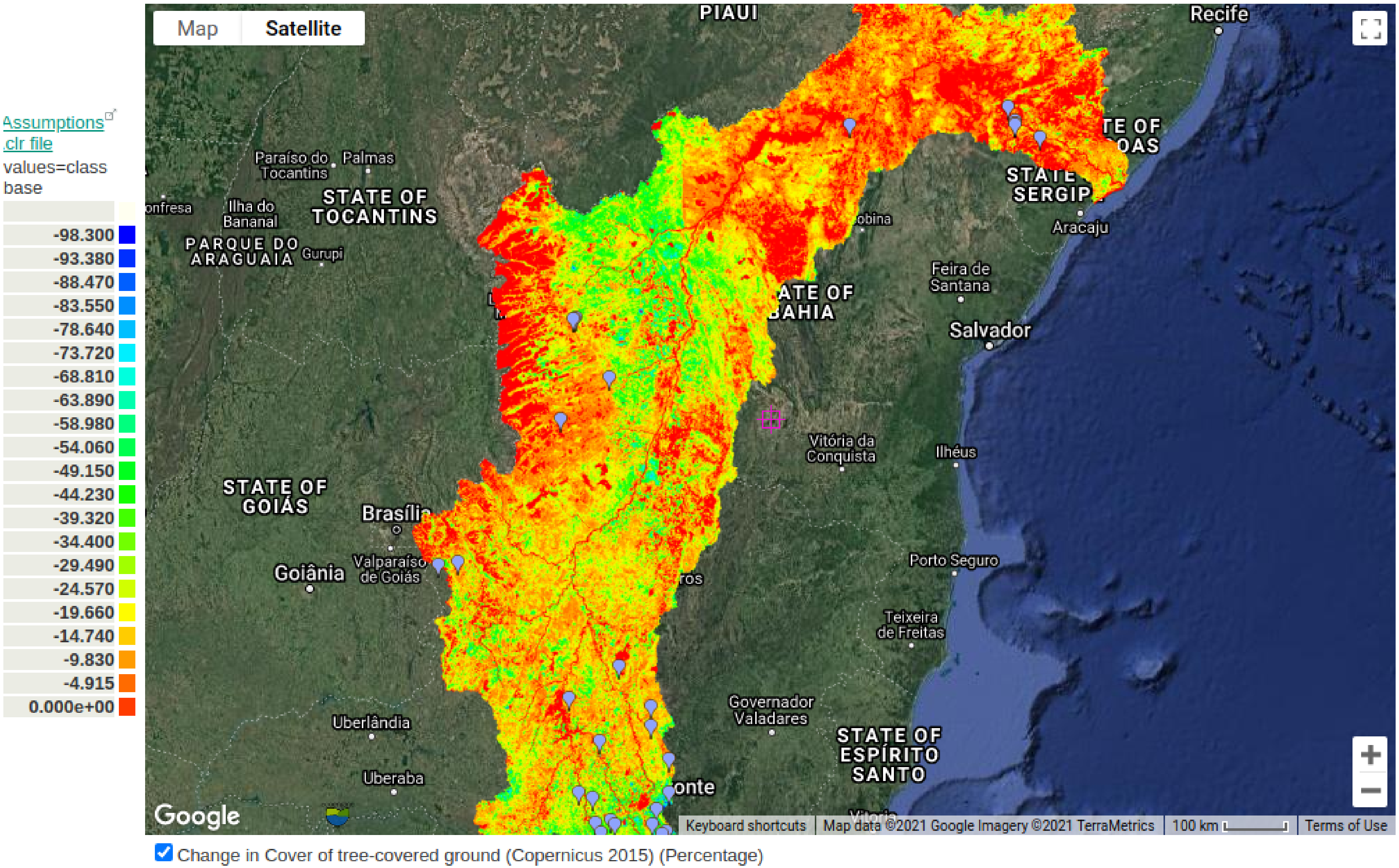
The metrics are brought together in both tabular form (figure 3) and as summary graphics (figures 4 to 9). The deforestation and reforestation scenarios applied led to the changes in tree cover shown in box 1.

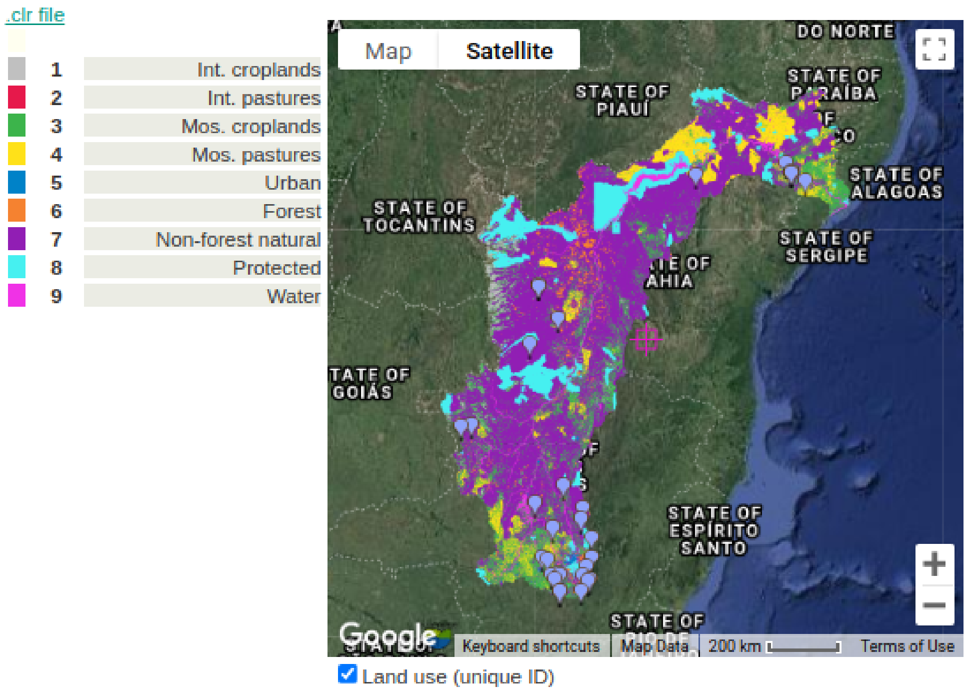
From figure 2 we can see for **34 Sao Francisco** HEP dams that:

- Only 4 HEP dams in the basin have significant protected area upstream, indicating the need for greater protection.
- Most of the dams have significant upstream semi-natural area (not agriculture, grazing land, urban, road,mining, oil & gas)
- Only two dams have majority forest cover upstream.
- Annual water provision to dams by semi-natural areas is >75% of flow for most dams and a little higher in the dry season (monthly maximum). >80% of sediment retention for most dams is in semi-natural areas, indicating the importance of these.
- The water quantity delivered to dams from fog interception is <10% of flow for all dams, but reaches a monthly maximum of >30% for 8 dams. Cloud forests are not very important to most HEP in the Sao Francisco.
- The hydrological influence of upstream protected areas reaches 100% of flow for two dams but is only above 30% of flow for 6 of the dams, but this is greater in the dry season for a few of the dams. Greater protection is needed to ensure inputs to dams are also protected.
- The hydrological influence of most dams is influenced >50% of flow by unprotected non-forest semi-natural land. This is a clear priority for investment.
- The hydrological influence of upstream unprotected forests is >30% of flow for around half of the dams, sometimes increasing by a further 10% of flow in the dry season
- The hydrological influence of cloud-affected forests is only significant for 3 dams
- All but 3 dams have low levels of current polluted water inputs
- Recent deforestation has influenced all dams less than 5% of flow
- Human land uses (urban, roads, agriculture, mining, oil & gas) contribute more than 30% of flow for 75% of the dams and greater than 75% of flow for only a few dams, especially in the dry season
- Projecting recent deforestation rates forward by 100 years affects the flow to around half of dams by >50%, it leads to increases rather than decreases in flow and increases sediment transport into the dams significantly for around half of the dams
- Projecting recent forest recovery rates forward 100 years significantly affects 3/4 of the dams. It does not lead to increases in water yield on an annual basis but does so for the driest month for most dams (increases generally <5% of flow). The decrease in sediment transport to the dams is significant for 3/4 of them, with decreases upto 100%

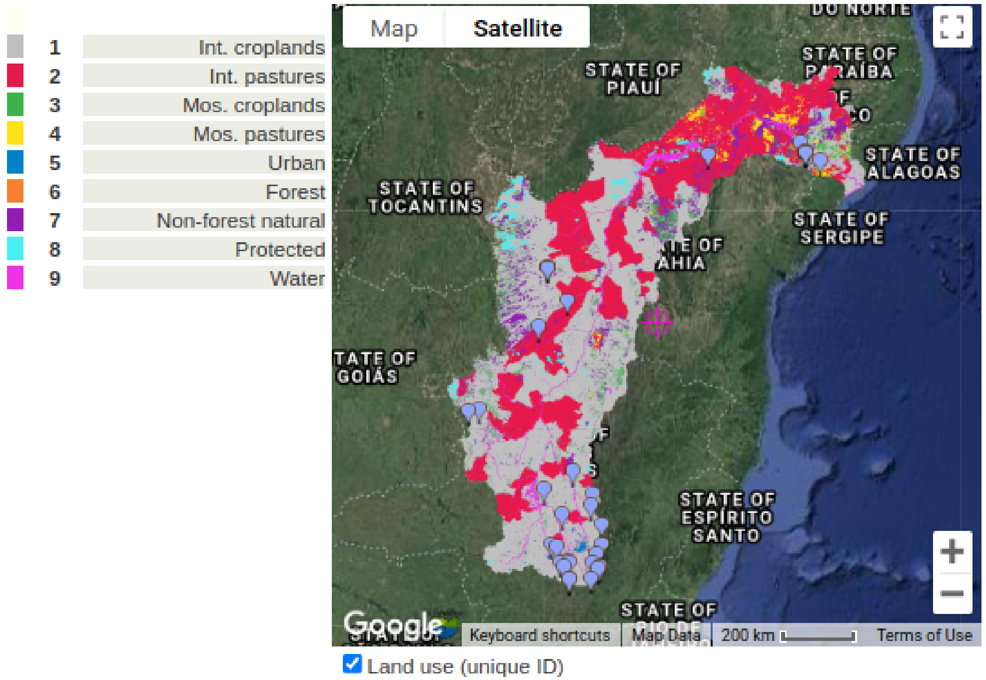
- By way of summary: these dams have a middling current **state** of green infrastructure because of low levels of forest and protected area but high levels of non-forest, natural land. Nature **contributes** more than 50% of flow to almost all of the dams, of which investable unprotected natural assets provide significantly to half of dams. Risks are <10% for 3/4 of the dams and the applied restoration scenario could positively affect more than 30% of flow for 3/4 of the dams.
- **Many of the dams are a high priority as shown in box 2 in list and map form, but the highest priorities (at 100%) are:**
    - **1014483:Cajuru (7 MW)**
    - **1112705:Caixao (1 MW)**
    - **1034301:Três Marias (396 MW)**
    - **1014475:Gafanhoto (12 MW)**
    - **1113564:Agostinho Rodrigues (1 MW)**
    - **1104790:Retiro Baixo (82 MW)**
    - **1014505:Rio de Pedras (9 MW)**
    - **1110853:Coronel Americo Teixeira (5 MW)**
- **These priorities are highly influenced by the spatial footprint of the deforestation and reforestation scenarios**

Deforestation scenario change in tree cover, indicating continued deforestation in areas where tree cover losses have been observed over the last decades



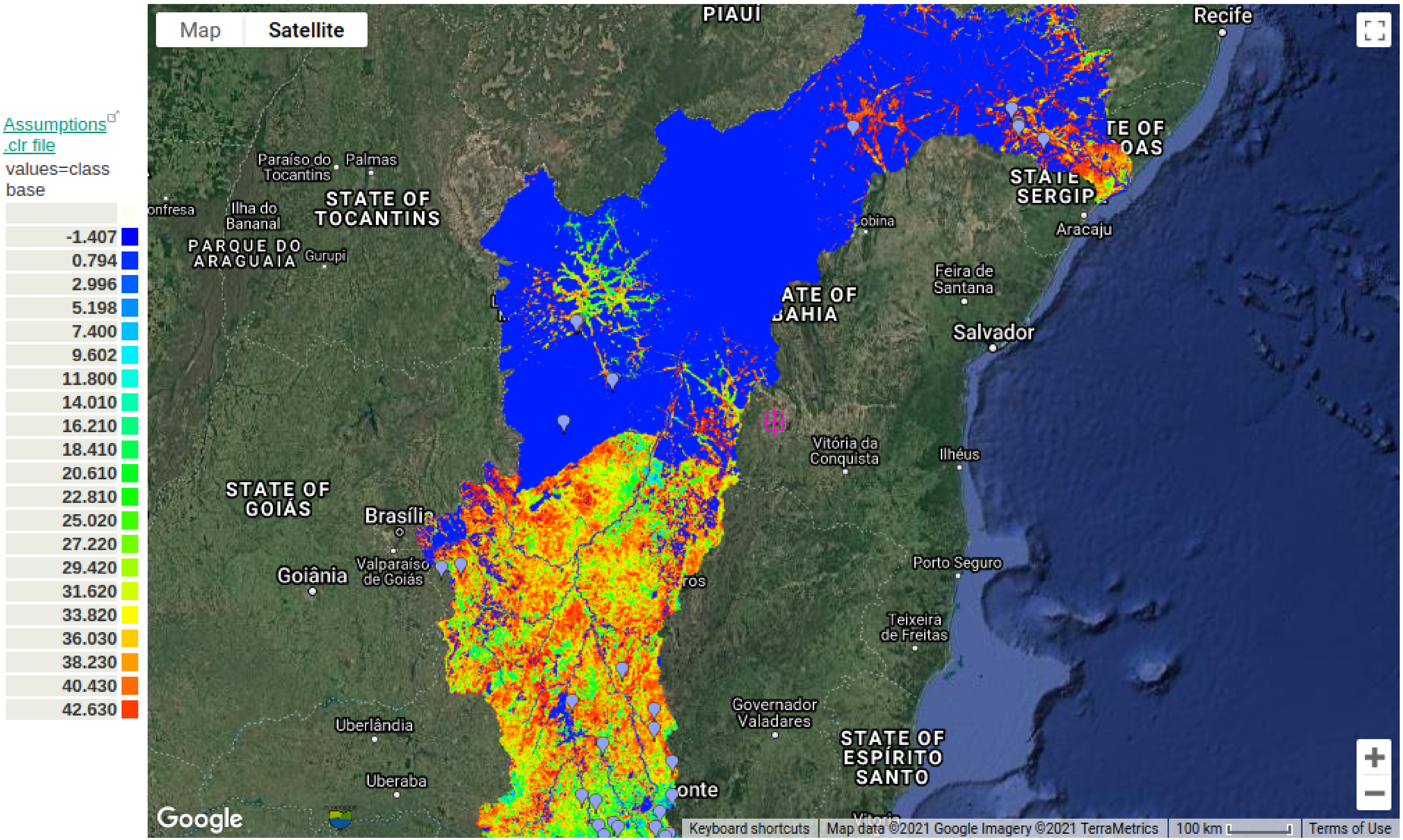


Baseline land use

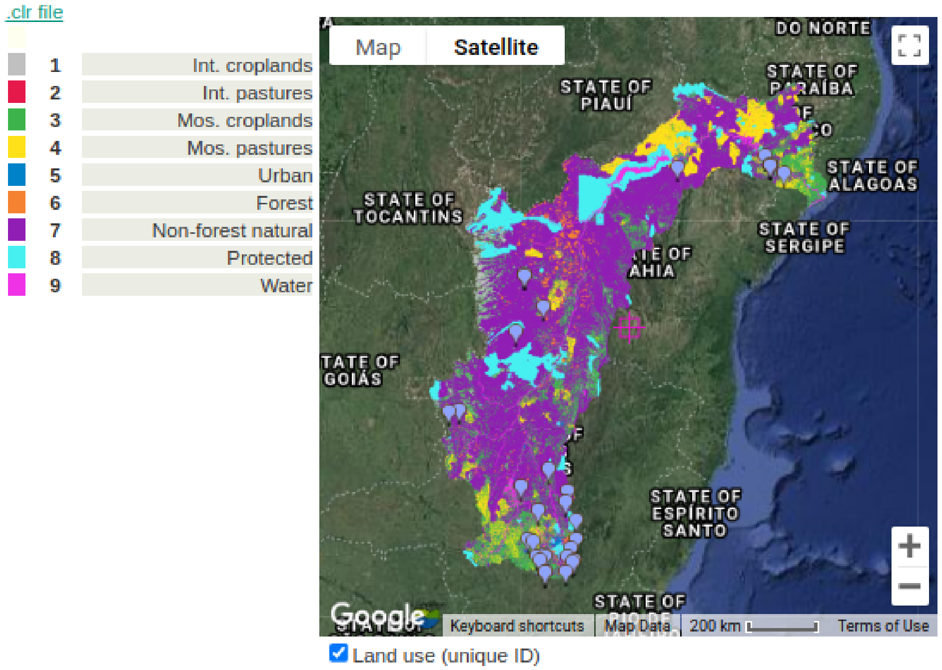


After deforestation scenario

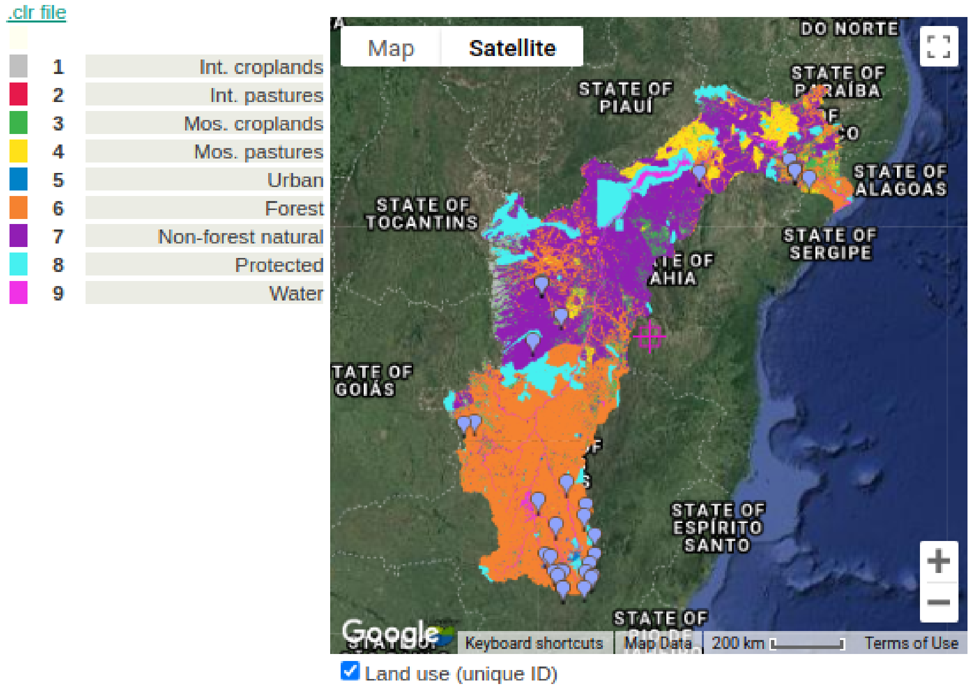
Reforestation scenario change in tree cover, indicating continued recovery in areas where tree cover gains have been observed over the last decades



Change in Cover of tree-covered ground (Copernicus 2015) (Percentage)



Baseline land use

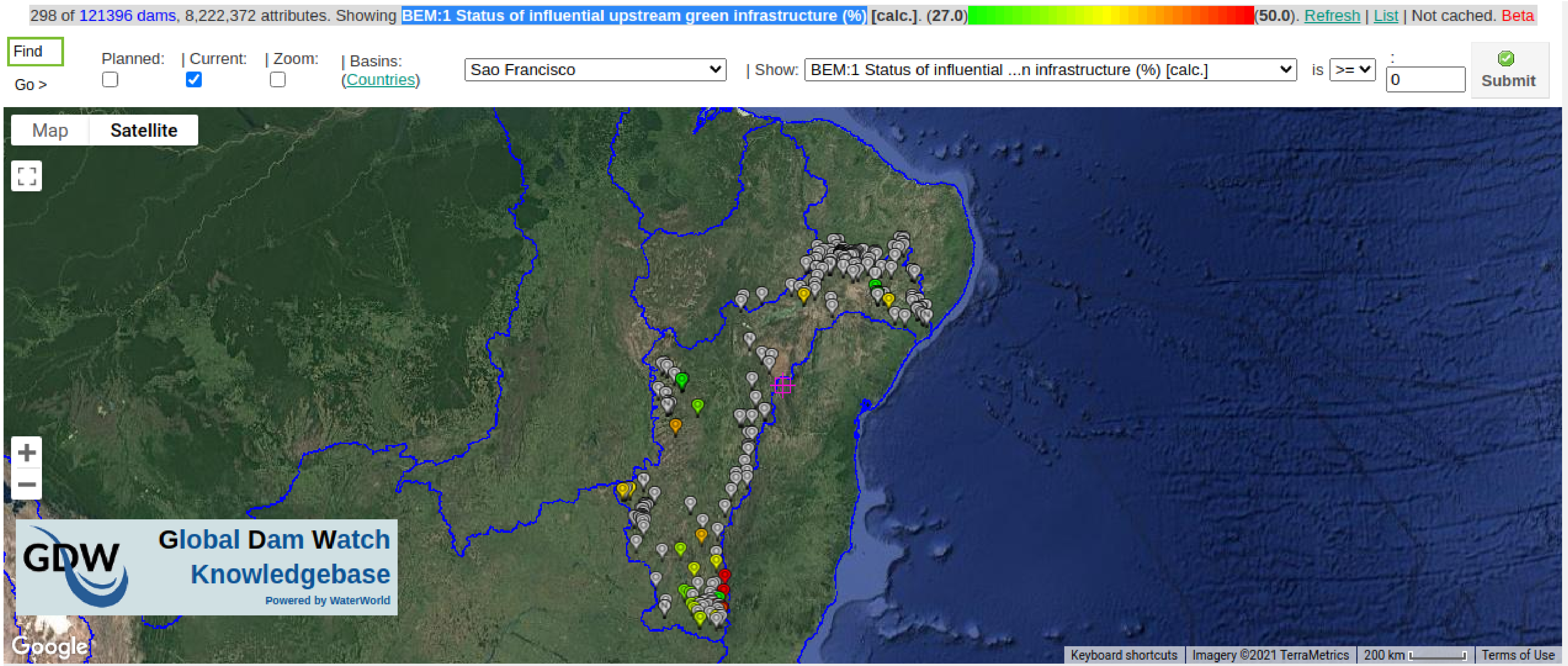


After reforestation

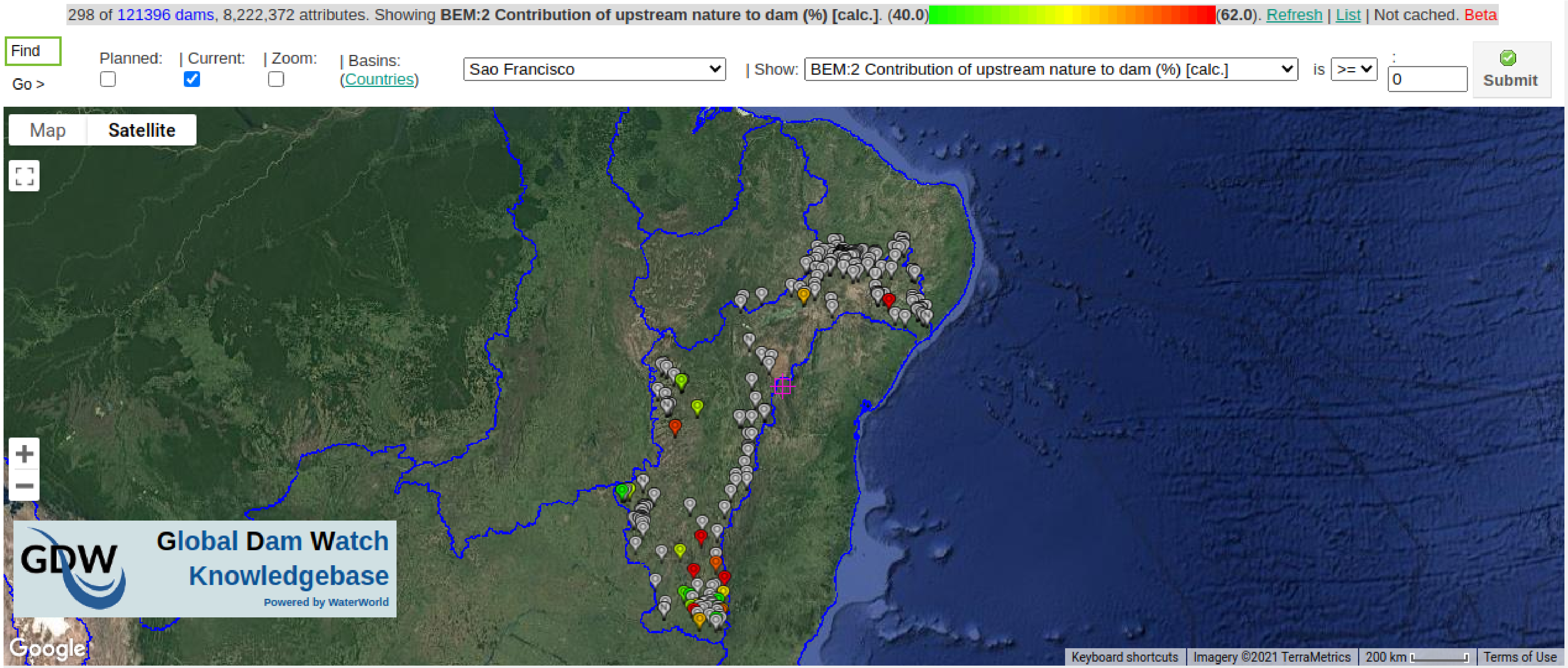
Box 1 The scenarios applied

	The overall priority for investment
1110853:Coronel Americo Teixeira (5 MW)	100
1110912:Piloto (2 MW)	81
1000847:Apolonio Sales (400 MW)	91
1015774:Paulo Afonso 4 (2462 MW)	-
1113576:Alto Femeas I (10 MW)	60
1110922:Unaí Baixo (26 MW)	86
1014491:Sobradinho Main Dam (1050 MW)	86
1034722:Itaparica (1479 MW)	-
1110845:Marzagao (3a unidade) (2 MW)	33
1110847:Pitangui (Cachoeira Bento Lopes) (1 MW)	95
1110848:Madame Denise (Cachoeira do Furado) (2 MW)	85
1014505:Rio de Pedras (9 MW)	100
1104790:Retiro Baixo (82 MW)	100
1014501:Parauna (4 MW)	88
1100397:Xingo (3162 MW)	94
1110893:Rieger (2 MW)	60
1114053:Presidente Goulart (8 MW)	61
1112431:G (2 MW)	92
1114175:Serra das Agulhas (30 MW)	79
1113564:Agostinho Rodrigues (1 MW)	100
1113820:Pratudao (1 MW)	58
1114130:Salto do Paraopeba (2 MW)	67
1110874:Santa Helena (5 MW)	82
1014475:Gafanhoto (12 MW)	100
1094026:UHE Paulo Afonso III (794 MW)	91
1110839:Doutor Augusto Goncalves (1 MW)	96
1114221:Sitio Grande (25 MW)	60
1000857:Queimado (105 MW)	68
1034301:Três Marias (396 MW)	100
1113885:Joao de Deus (1 MW)	78
1110944:Maria Celia Mauad Notini (1 MW)	89
1110943:Nova Dorneles (Ex-Dorneles) (4 MW)	96
1112705:Caixao (1 MW)	100
1014483:Cajuru (7 MW)	100

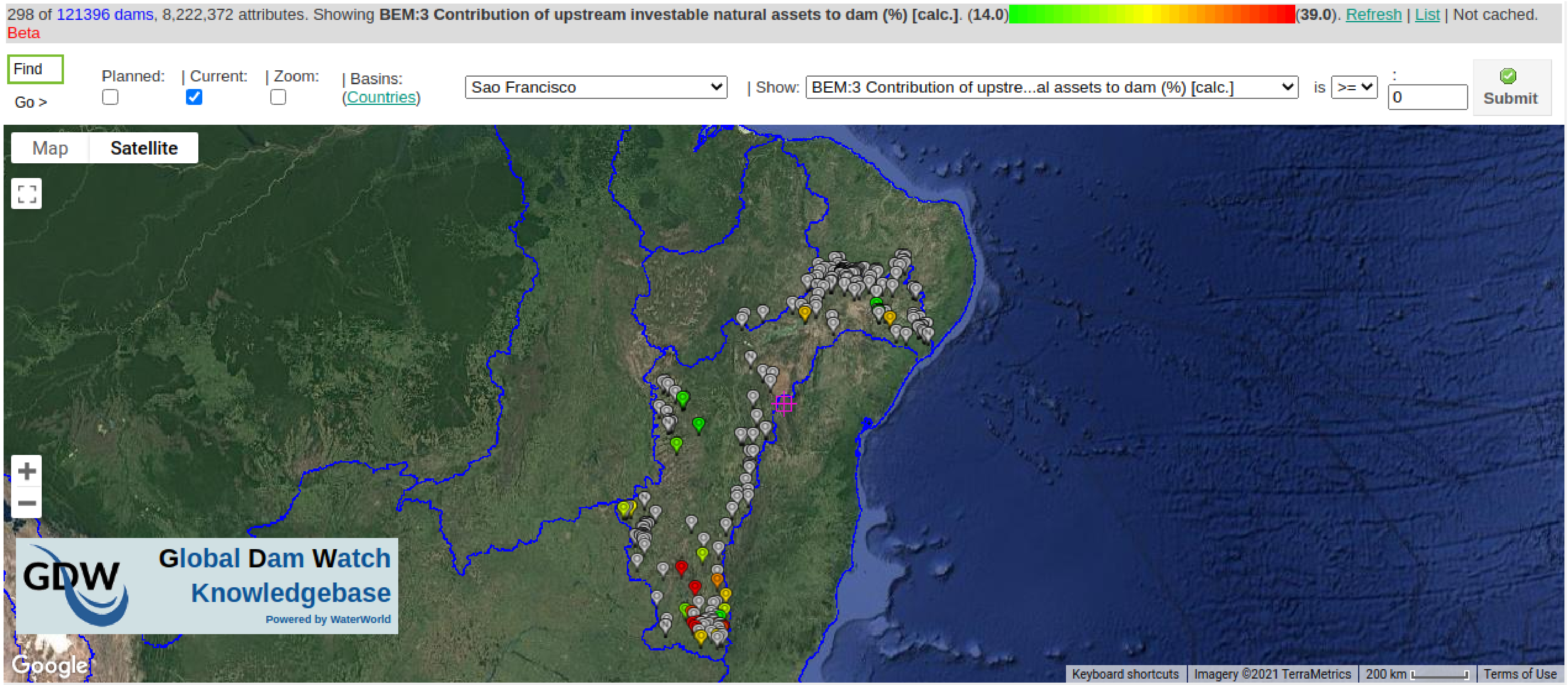
Overall priority for HEP dams in the Sao Francisco



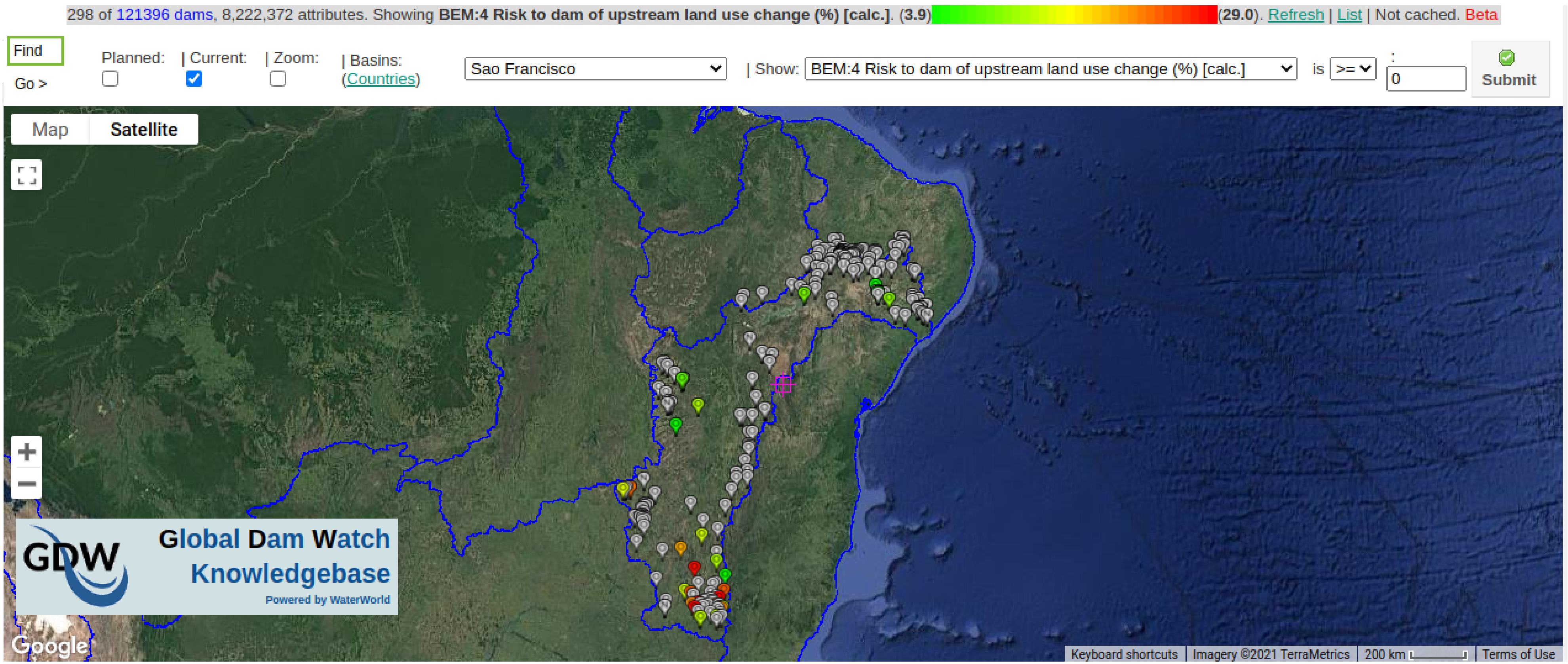
BEM:1 Status of influential upstream green infrastructure (%).Grey icons are not HEP dams.



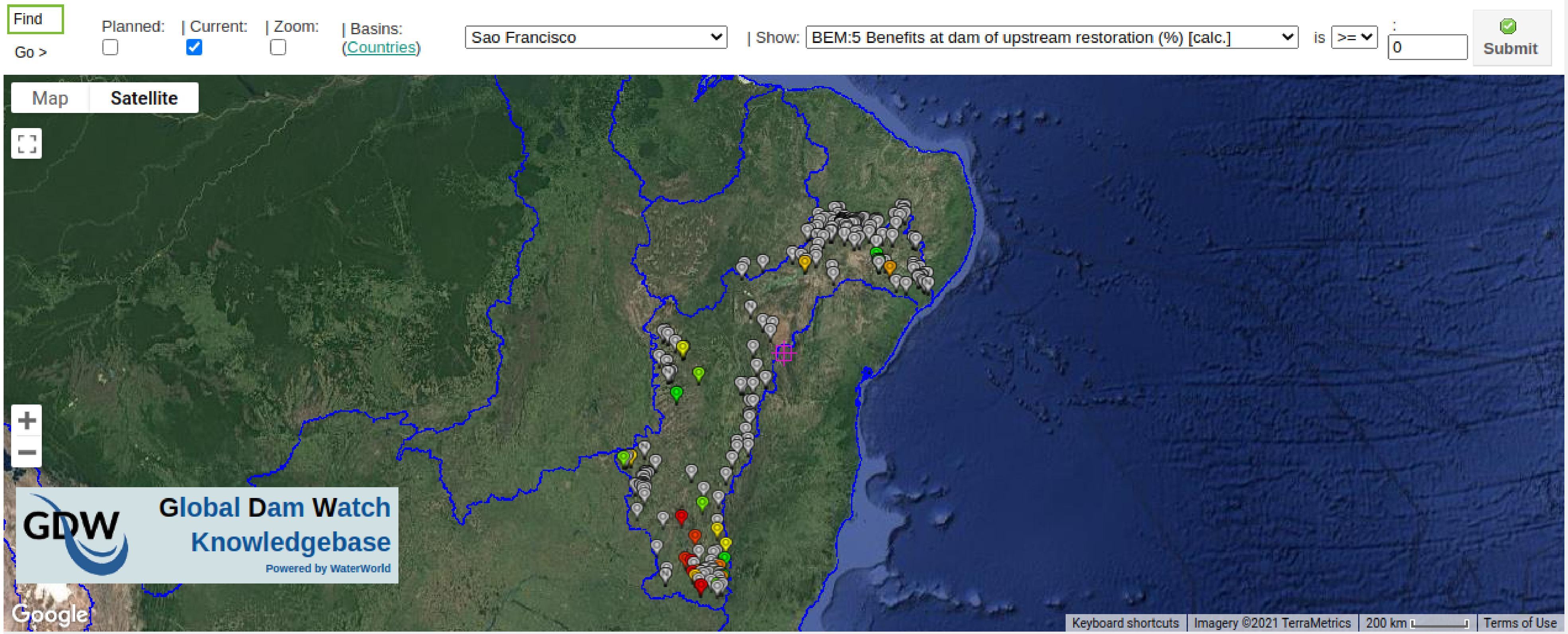
BEM:2 Contribution of upstream nature to dam (%).Grey icons are not HEP dams.



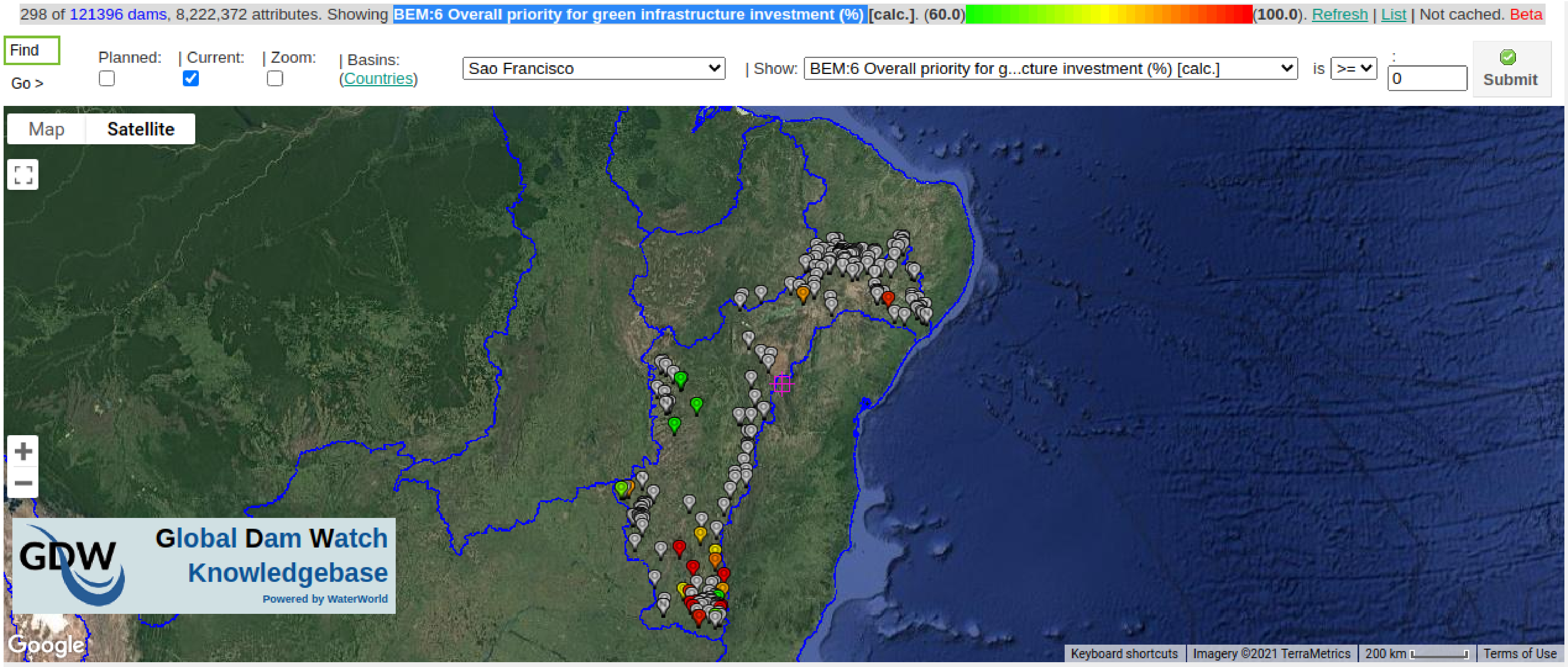
BEM:3 Contribution of upstream investable natural assets to dam (%).Grey icons are not HEP dams.



BEM:4 Risk to dam of upstream land use change (%).Grey icons are not HEP dams.



BEM:5 Benefits at dam of upstream restoration (%).Grey icons are not HEP dams.

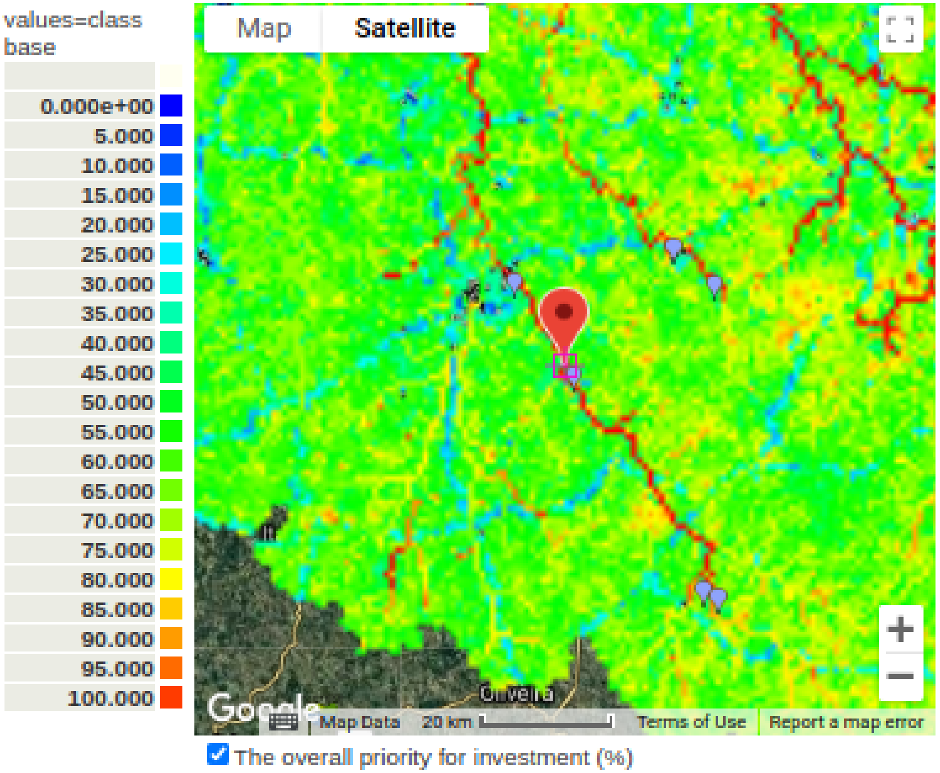


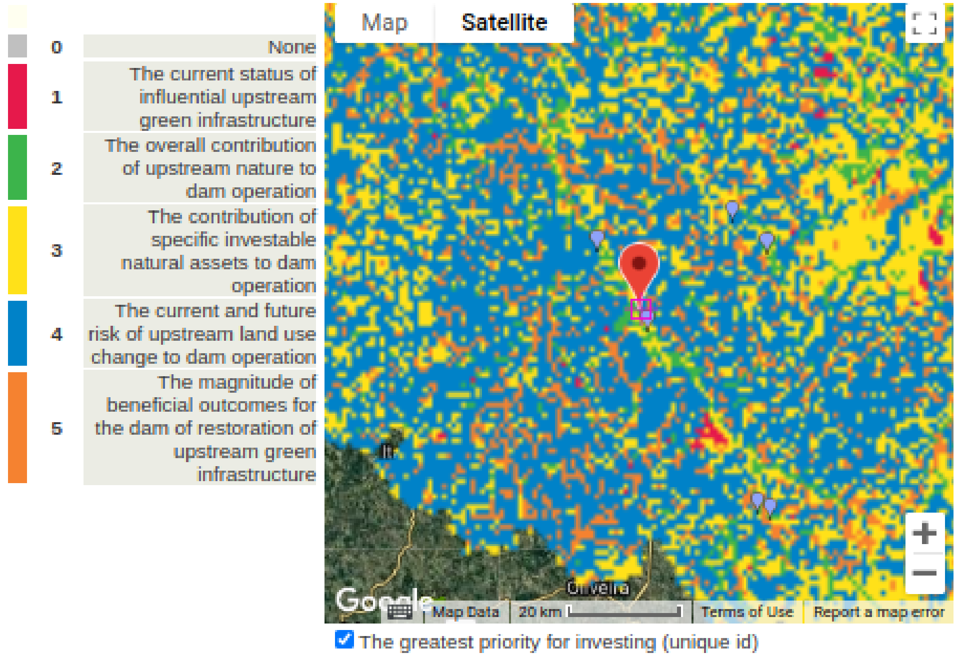
BEM:6 Overall priority for green infrastructure investment (%).Grey icons are not HEP dams.

Box2: Priorities for HEP dams in the Sao Francisco

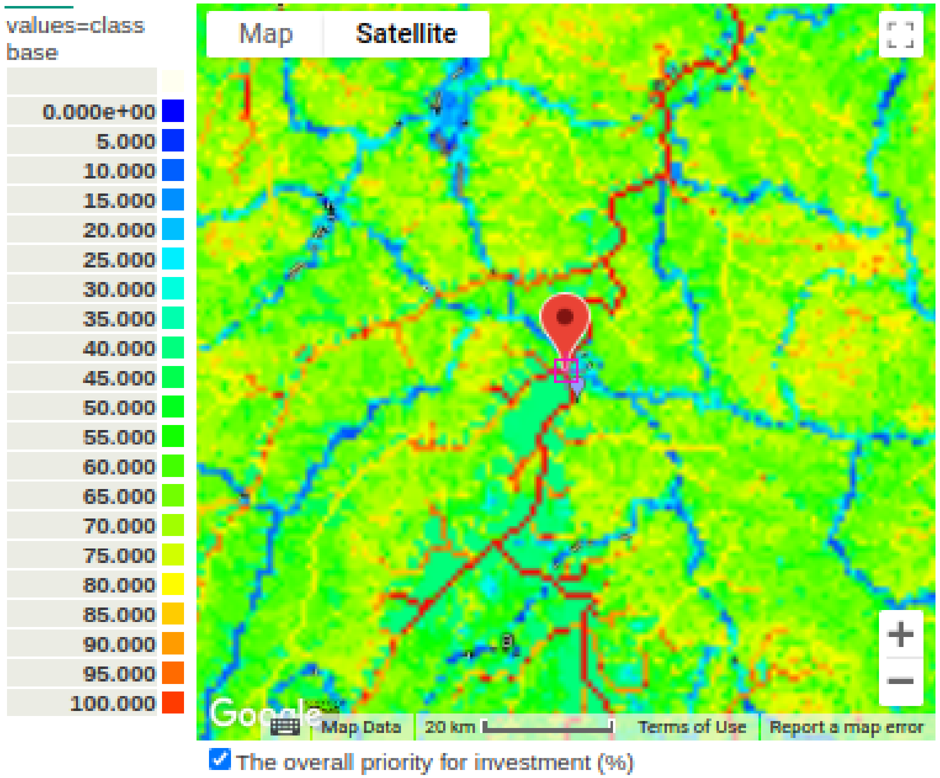
Example priority maps are shown for some of these dams in box 3 below.

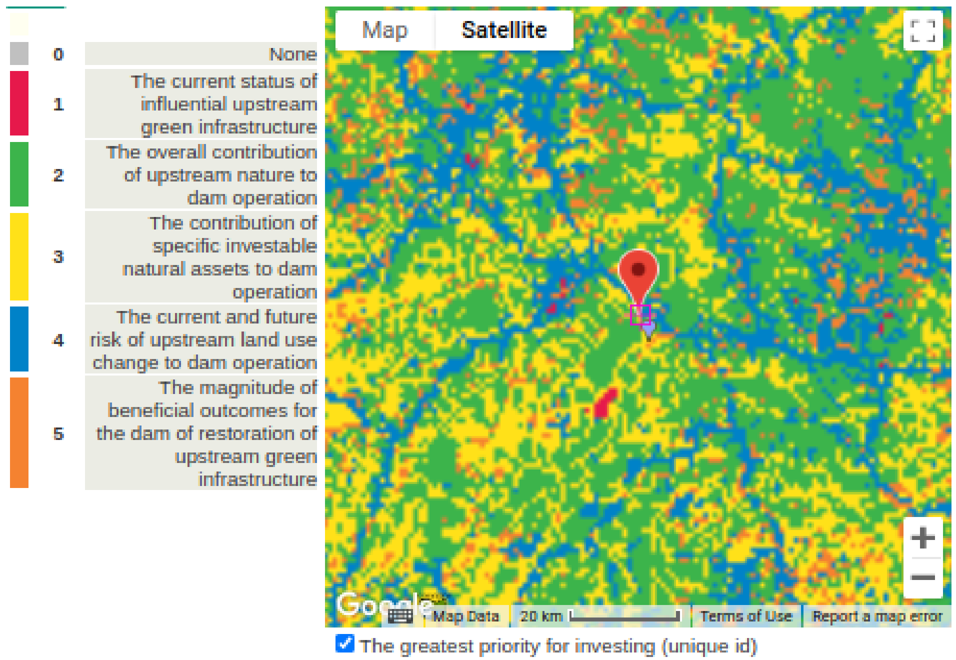
1014483:Cajuru (7 MW)



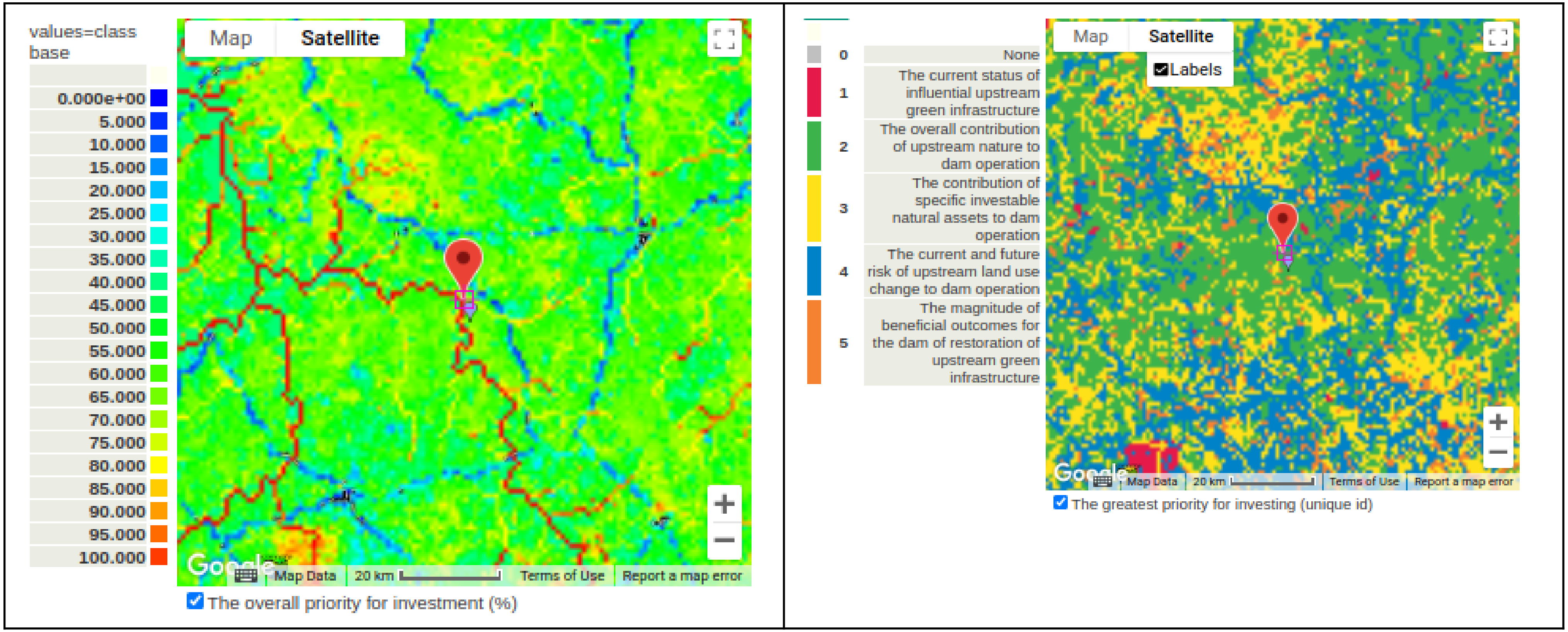


1034301:Três Marias (396 MW)





1104790:Retiro Baixo (82 MW)



Box 3: priority scores for the highest priority dams

Figures 4 to 9 show the same metrics in radar diagrams in which it is easier to separate different types of catchment in terms of their response. Table 4 show the mapped outputs corresponding to these data at dams

	Upstream protected area (%)	Upstream semi-natural area (%)	Upstream forest area (%)	Annual water provision by semi-natural areas (% of total)	Maximum monthly water provision by semi-natural areas (% of total)	Upstream sediment retention (deposition) by semi-natural areas (% of total)	Annual water quantity from fog interception (% of total)	Monthly maximum water quantity from fog interception (% of total)	Hydrological influence of upstream protected areas (%)	Monthly maximum hydrological influence of upstream protected areas (%)	Hydrological influence of unprotected upstream non-forest, semi-natural areas (%)	Monthly maximum hydrological influence of upstream, unprotected non-forest, semi-natural areas (%)	Hydrological influence of upstream unprotected forests (%)	Monthly maximum hydrological influence of upstream unprotected forests (%)	Hydrological influence of upstream cloud-affected forests (%)	Monthly maximum hydrological influence of upstream cloud-affected forests (%)	Current human footprint on water quality (%)	Hydrological influence of recent upstream deforestation (% of inputs)	Hydrological influence of recent upstream afforestation (% of inputs)	Hydrological influence of all upstream intervened land (% of inputs)	Monthly maximum hydrological influence of all upstream intervened land (% of inputs)	Hydrological influence of upstream 'defor' deforestation scenario (% of inputs)	Decrease in water yield due to upstream 'defor' deforestation scenario (%)	Maximum monthly decrease in water yield due to upstream 'defor' deforestation scenario (%)	Increase in sediment transport due to upstream 'defor' deforestation scenario (%)	Hydrological influence of upstream 'refor' restoration scenario (% of inputs)	Increase in water yield due to upstream 'refor' restoration scenario (%)	Maximum monthly increase in water yield due to upstream 'refor' restoration scenario (%)	Decrease in sediment transport due to upstream 'refor' restoration scenario (%)	The current status of influential upstream green infrastructure	The overall contribution of upstream nature to dam operation	The contribution of specific investable natural assets to dam operation	The current and future risk of upstream land use change to dam operation	The magnitude of beneficial outcomes for the dam of restoration of upstream green infrastructure	The overall priority for investment
1110853:Coronel Americo Teixeira (5 MW)	99	98	14	98	98	99	8.1	2.6	100	100	2.1	2.2	0.29	0.31	3.8	3.9	0.22	0.082	0.028	3.7	3.7	25	0	2.1	0.011	100	0	7.9	0.01	70	61	27	3.9	27	100
1110912:Piloto (2 MW)	12	81	21	78	80	91	5	42	9.2	21	49	93	18	33	0.7	0.68	25	3.6	1.6	20	34	19	0	0.4	6.6	49	0	0.38	13	38	59	28	12	16	81
1000847:Apolonio Sales (400 MW)	12	81	21	78	80	91	5	40	9.2	21	49	93	18	33	0.7	0.68	18	3.6	1.6	20	34	19	0	0.4	0	49	0	0.39	76	38	59	28	11	31	91
1015774:Paulo Afonso 4 (2462 MW)	0	14	6.8	-	-	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	7.7	0	0	0	18	7.1	-	0	2	4.5	-
1113576:Alto Femeas I (10 MW)	0	71	9.8	68	69	87	2.9	4.7	0	0	39	63	5.7	9.6	0	0	3.2	5.5	0.27	21	31	4.6	0	0	0	5.9	0	0	100	27	46	15	7.3	26	60
1110922:Unaí Baixo (26 MW)	30	69	14	68	69	78	6.5	13	35	43	44	56	11	13	0	0	19	0.83	0.3	33	39	13	0	0	89	39	0	0	76	38	47	25	22	29	86
1014491:Sobradinho Main Dam (1050 MW)	13	82	22	78	80	91	5.1	11	9.2	20	50	91	18	32	0.71	0.76	1.9	3.6	1.7	20	33	19	0	0.74	0	50	0	0.71	71	39	53	28	8.9	30	86
1034722:Itaparica (1479 MW)	0	62	5.8	-	-	0	0	0	0	0	0	0	0	0	0	0	0.029	0	0	0	0	0	0	0	0	0	0	0	0	23	-	0	0.0032	0	-
1110845:Marzagao (3a unidade) (2 MW)	0	0	19	0	0	0	4	5.9	0	0	0	0	17	19	0	0	10	0.48	0	86	100	16	0	3.2	90	73	0	8.2	62	6.2	2	4.4	34	36	33
1110847:Pitangui (Cachoeira Bento Lopes) (1 MW)	0	63	34	63	63	31	9.9	3	0	0	71	83	58	68	0.55	0.63	4.6	3	5	62	73	58	0	0.7	0	95	0	0.52	100	32	34	35	23	49	95
1110848:Madame Denise (Cachoeira do Furado) (2 MW)	14	81	56	81	81	79	6.1	7.7	16	16	25	28	44	50	4.3	4.7	1.9	2.6	2.3	17	19	51	0	9.6	100	31	0	2.1	11	50	51	23	23	11	85
1014505:Rio de Pedras (9 MW)	55	83	53	83	83	84	7.9	8.5	67	67	20	21	23	24	48	49	1.1	0.74	0.55	20	20	63	0	11	0.085	41	0	3.1	0	64	53	40	13	11	100
1104790:Retiro Baixo (82 MW)	5.1	72	30	72	72	83	11	100	11	12	82	98	52	61	1.8	6.7	41	8	3.3	51	60	56	0	1.9	25	100	0	1.2	57	36	67	41	27	40	100
1014501:Parauna (4 MW)	0	65	25	85	85	96	4.4	12	0	0	75	77	30	30	17	18	13	0.78	1.3	18	18	30	0	12	0	87	0	18	0	37	57	31	11	28	88
1100397:Xingo (3162 MW)	12	81	20	78	80	90	5	69	9.2	21	49	94	18	33	0.7	0.68	6.9	3.6	1.6	20	34	19	0	0.34	0	50	0	0.35	77	38	64	28	6.5	32	94
1110893:Rieger (2 MW)	0	70	9.8	68	69	87	2.9	4.7	0	0	39	63	5.6	9.6	0	0	2.1	5.5	0.27	21	31	4.6	0	0	0	64	0	0	100	27	46	15	7.2	26	60
1114053:Presidente Goulart (8 MW)	0.023	82	14	74	81	69	3.4	0.1	0.022	0.038	24	68	3.7	14	0	0	3.4	0	0.059	9.3	19	3.3	0	0	60	0.11	0	0	77	32	47	14	11	19	61
1112431:G (2 MW)	100	60	18	57	59	0	11	2.3	100	100	0	0	0	0	38	41	0.24	3.1	1.5	85	88	38	0	2.3	1.9e-28	95	0	3.0	0.0059	59	28	35	25	25	92
1114175:Serra das Agulhas (30 MW)	0	91	17	91	91	99	4.2	0	0	0	66	76	15	17	3	3.2	1.1	0.34	0.31	9.3	9.1	15	0	4.1	54	78	0	13	6.5	36	58	22	10	24	79
1113564:Agostinho Rodrigues (1 MW)	8.1	87	39	87	87	94	7.9	9.9	10	11	56	57	45	46	27	28	5.6	0.86	0.75	16	16	47	0	5.2	100	65	0	3.1	70	45	57	35	21	35	100
1113820:Pratudao (1 MW)	18	92	13	92	92	97	3.5	6	12	20	32	67	4.9	10	0	0	0.35	1.6	0.0011	4.3	8.5	6.2	0	0	0	0	0	0	0	41	58	18	2.3	0	58
1114130:Salto do Paraopeba (2 MW)	3.3	73	33	73	73	37	7.4	9.5	4.6	4.9	50	53	35	37	11	13	3.9	1.9	1.8	29	31	36	0	5.4	0	64	0	3.6	0.57	37	40	26	12	17	67
1110874:Santa Helena (5 MW)	0.77	99	19	99	99	99	4.4	6.5	0.47	0.68	63	79	15	19	0	0	0.11	1.3	3	0.89	1.1	5.3	0	1	100	65	0	0	0	40	62	22	13	18	82
1014475:Gafanhoto (12 MW)	0	69	34	69	69	79	10	3.2	0	0	82	95	61	70	1.2	1.4	3.1	2.6	4.9	56	64	60	0	1.1	0	100	0	1	100	34	46	39	21	50	100
1094026:UHE Paulo Afonso III (794 MW)	12	81	21	78	80	91	5	42	9.2	21	49	93	18	33	0.7	0.68	12	3.6	1.6	20	34	19	0	0.4	0	49	0	0.38	76	38	59	28	10	32	91
1110839:Doutor Augusto Goncalves (1 MW)	0	75	36	75	75	84	9.4	29	0	0	73	87	55	66	0	0	8.7	2	6.5	38	46	55	0	1.8	100	77	0	1.1	0	37	54	35	29	19	96
1114221:Sitio Grande (25 MW)	0	71	9.8	68	69	89	2.9	4.7	0	0	39	63	5.7	9.6	0	0	2.1	5.5	0.27	21	31	4.6	0	0	0	6	0	0	100	27	47	15	7.1	26	60
1000857:Queimado (105 MW)	37	67	12	66	67	52	5.9	9.1	37	45	35	47	7.4	9.7	0	0	8.2	0.78	0.27	31	38	9.9	0	0.028	41	29	0	0.34	41	39	40	23	14	18	68
1034301:Três Marias (396 MW)	2.8	71	27	71	71	88	9.6	2.6	6.3	6.7	83	100	46	56	1.6	1.9	2.1	3.5	5.1	50	62	47	0	1.1	0	100	0	0.94	100	34	48	38	19	50	100
1113885:Joao de Deus (1 MW)	0	64	32	64	64	74	5.7	8.9	0	0	40	47	29	35	0	0	7.4	1.8	3.1	33	39	29	0	5.5	0	58	0	4.6	100	32	43	19	13	41	78
1110944:Maria Celia Mauad Notini (1 MW)	0	72	32	72	72	79	6.6	13	0	0	59	60	39	40	0	0	7.6	0.76	2.1	34	35	38	0	1.4	0	74	0	1.2	100	34	48	25	13	44	89
1110943:Nova Dorneles (Ex-Dorneles) (4 MW)	0	75	31	75	75	62	7.2	48	0	0	64	68	38	40	3.3	3.7	3.1	0.99	3.6	31	32	38	0	3.1	0	80	0	3.1	100	35	53	27	12	46	96
1112705:Caixao (1 MW)	0	67	34	66	67	0.91	10	100	0	0	74	89	60	71	0	0	46	2.4	5.6	59	68	59	0	0.26	100	91	0	0.26	58	34	49	37	38	37	100
1014483:Cajuru (7 MW)	0	70	34	69	70	78	10	100	0	0	83	95	61	70	1.3	1.5	39	2.4	4.8	55	62	61	0	1.1	100	100	0	1.1	21	35	66	39	36	30	100

Figure 3 Output from WaterWorld GIBE module showing individual and compound metrics (columns) vs dams in the Sao Francisco basin (rows) to better understand the dependence of blue energy on green infrastructure. The columns are the different metrics and the rows are different dams. All metrics are to the same scale (0-100%) with red being low, yellow middling and green high. All HEP dams in the Sao Francisco basin are shown with values across all metrics

Future work

- Complete quality control on all HEP dams in Brazil in GlobalDamWatchKB (currently 1129 of 8838 total dams of all types)
- Snap all HEP dams to WaterWorld network
- Run WaterWorld each basin within Brazil (8 basins) for baseline, deforestation and reforestation scenarios
- Extract dam data and analyse using the GIBE tool in WaterWorld to identify dams with
    - **Current state:** A low current influence of green infrastructure and thus need to increase influence through **restoration and increased protection** for improved resilience of dam operations
    - **Overall contributions:** dams with significant contributions from existing green infrastructure indicating the need to ensure **protection of the existing** green infrastructure
    - **Contribution of investable assets:** indicating the particular assets contributing significantly to hydrological ecosystem services for specific dams to advise the most influential investment strategies for **specific green infrastructure assets**
    - **Risk to contributions:** identifying specific current and future risks to dams indicating where in the watershed investments in conservation will be **most effective to reduce risks to the dam**
    - **Benefits of restoration:** identifying dams which would **benefit significantly from restoring** degraded systems
- Put these indices together, alongside information on dam HEP capacity to provide the overall prioritization and guidance on business cases for priority dams

Open questions

- Whether there is anything missing in the analysis developed. We will also add the HEP capacities for each dam as part of the prioritisation exercise that we will do using these metrics
- We have run a BAU rates deforestation scenario forward for 100 years given that this is the average lifetime of a dam. This also produces significant deforestation. Would you prefer a different scenario
- We have run a BAU rates restoration scenario forward for 100 years given that rates of restoration are slow, so over 100 years we end up with significant afforestation

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Appendix 1 Figures

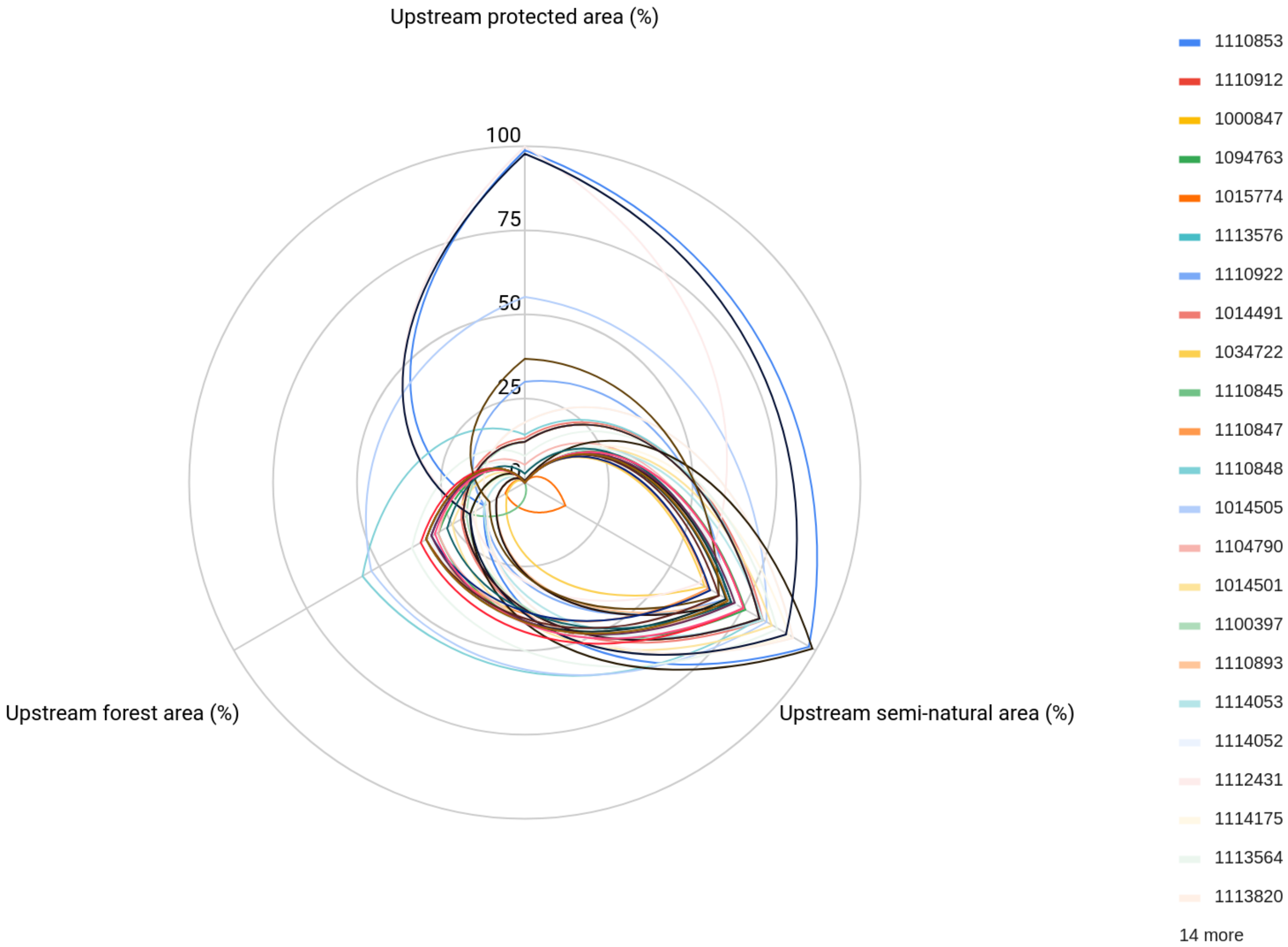


Figure 4 Radar chart for Sao Francisco basin indicating key metrics of state. Most basins are dominated by semi-natural areas, and have little protection, a few have much more significant protect. All have low forest cover

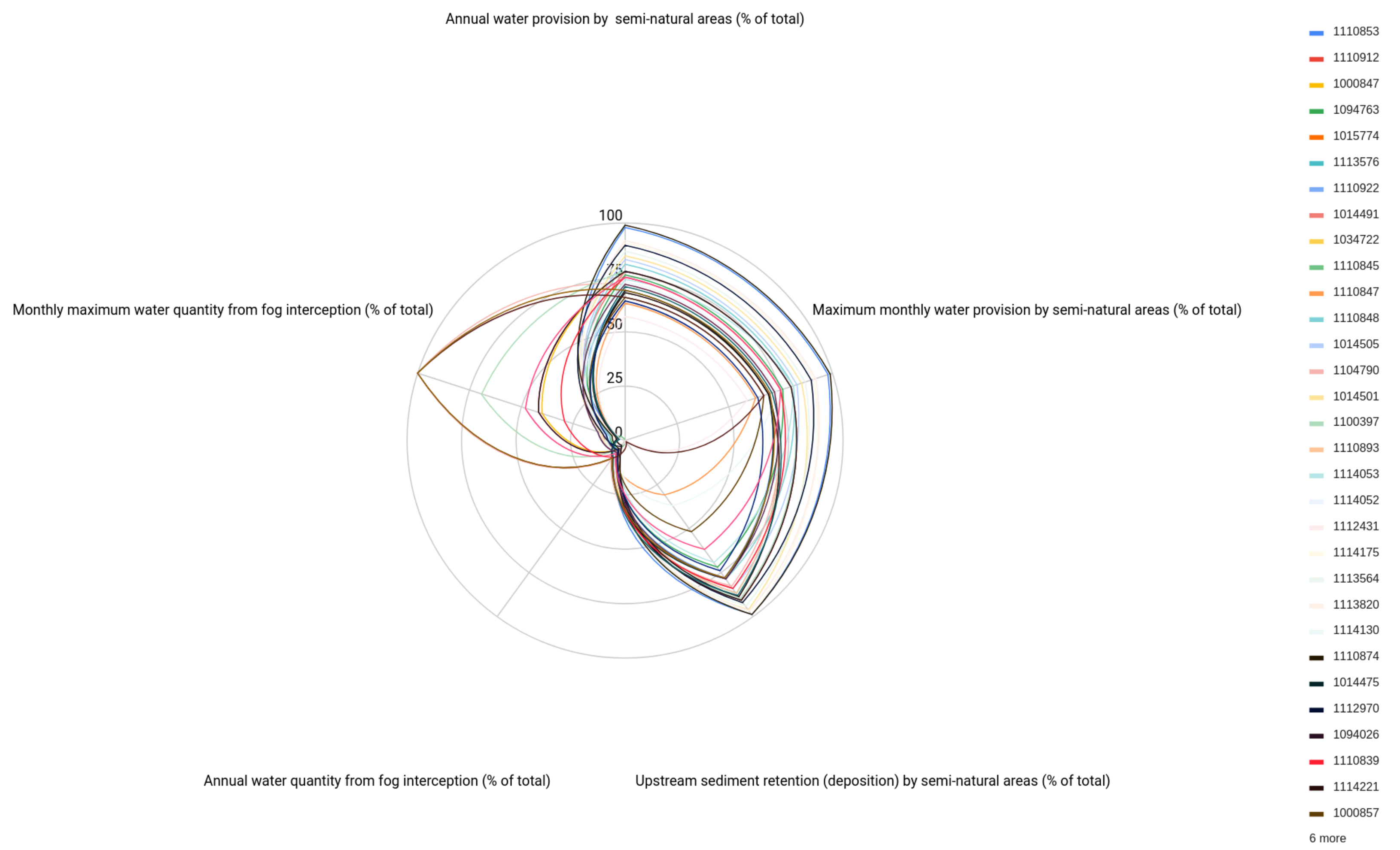


Figure 5 Radar chart for Sao Francisco basin indicating key metrics of nature's contribution. All basins contribute very little from fog but most have high sediment retention and annual monthly water provision by natural systems

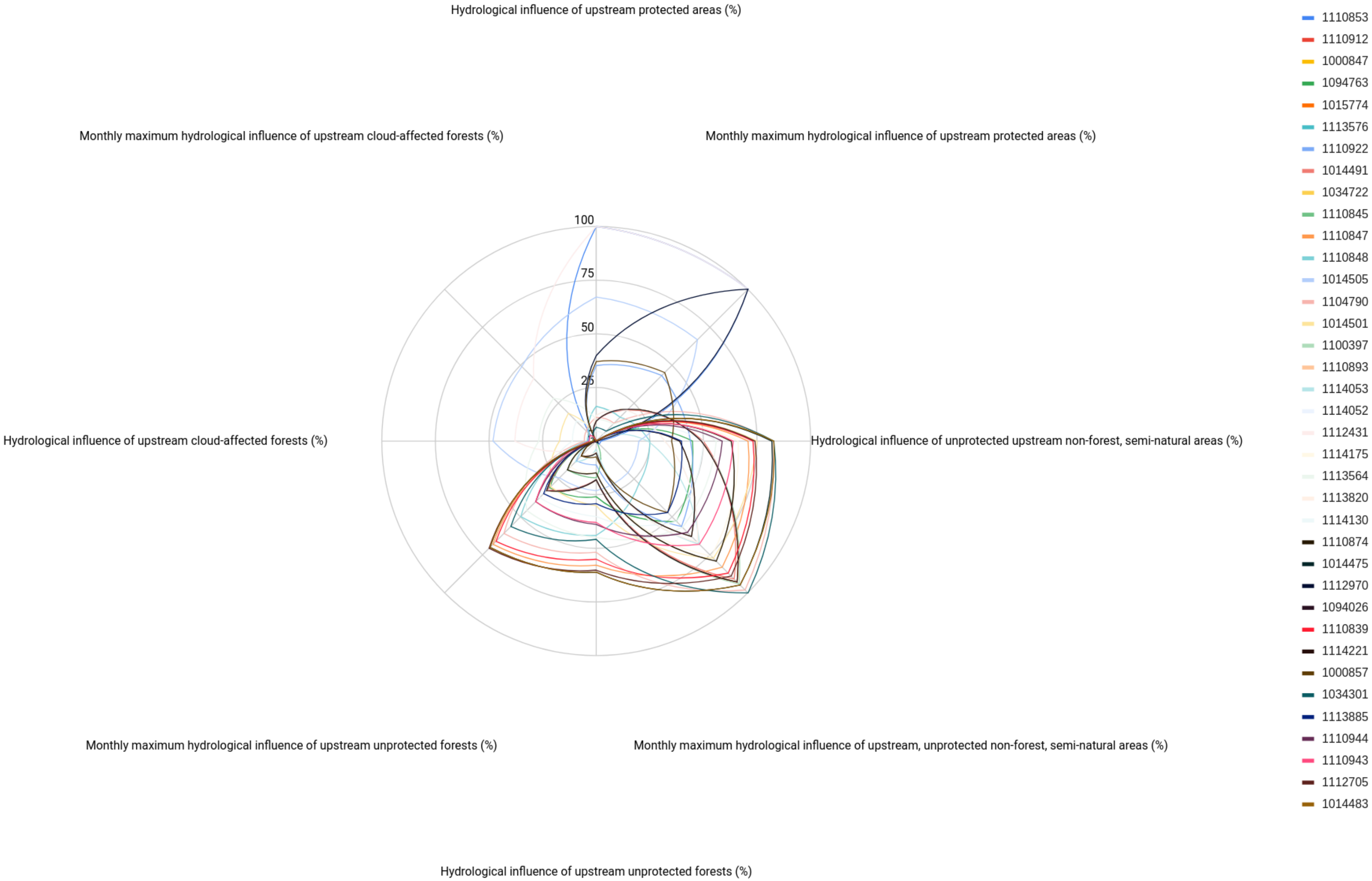


Figure 6 contributions from specific investable assets. For almost all dams the opportunities for influential investment are in unprotected forests and unprotected non-forest natural lands

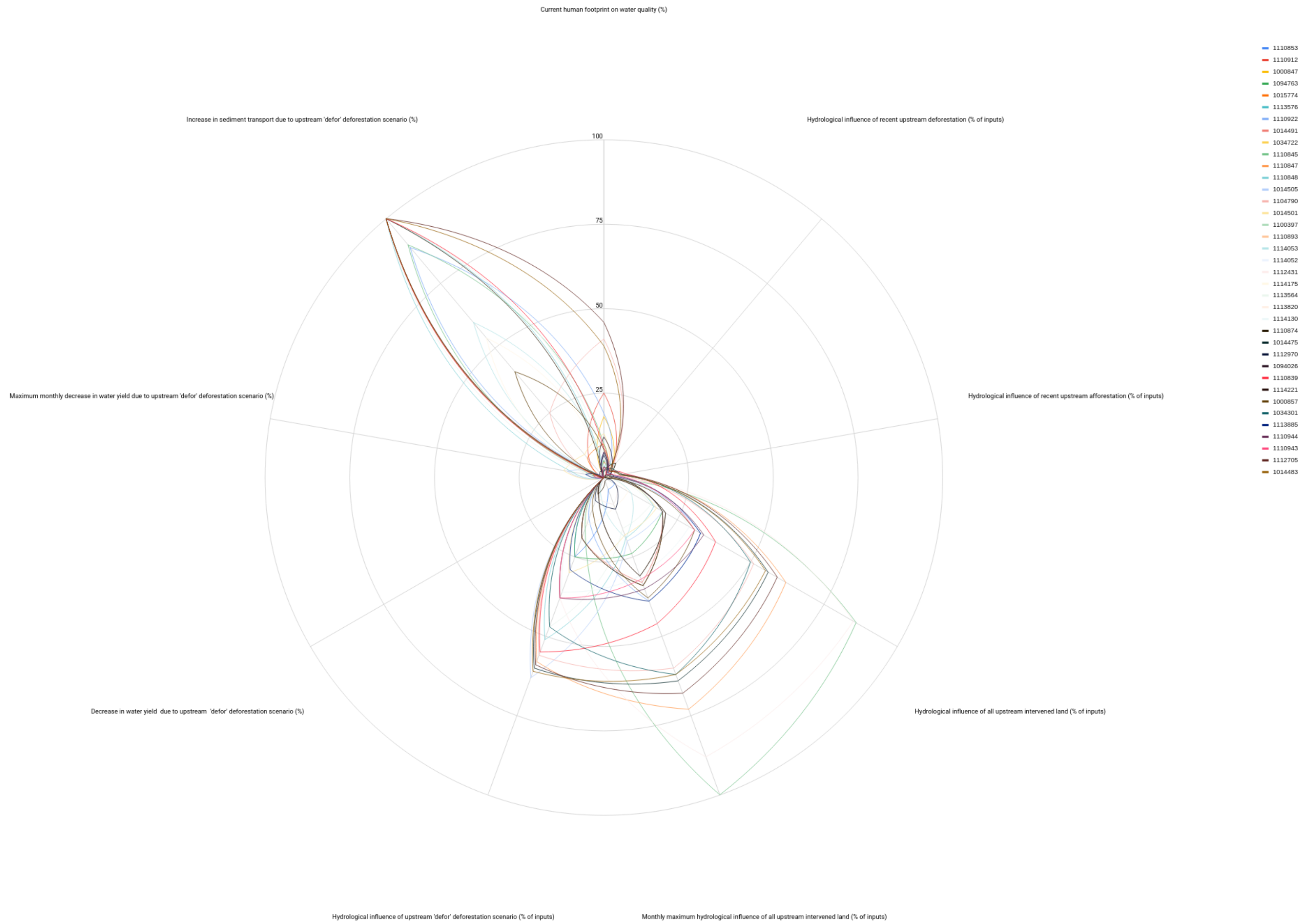


Fig 7 The greatest risks influencing flow to the dams are from currently intervened land and associated with the deforestation scenario (especially with respect to sediment inputs

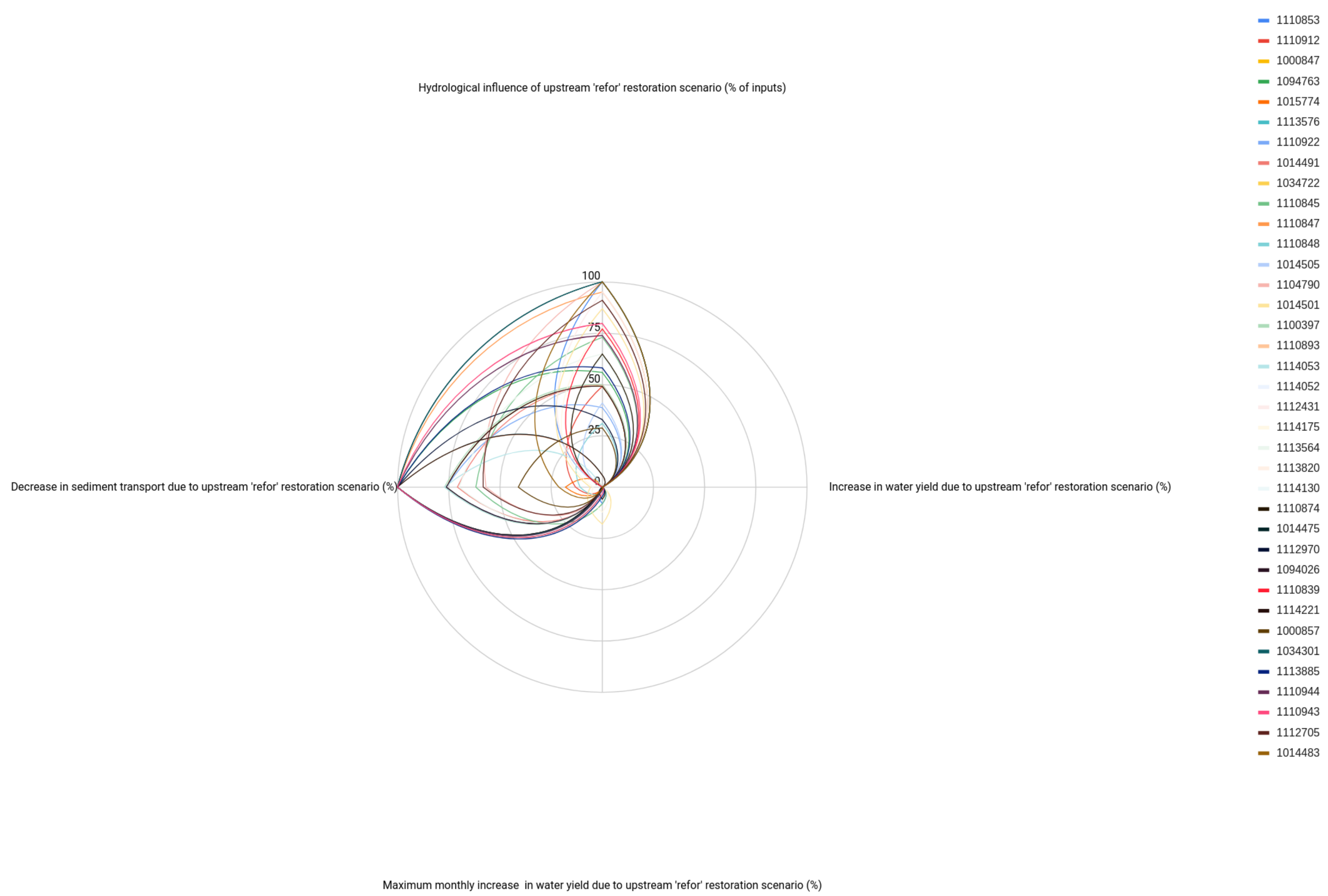


Fig 8 A BAU restoration scenario in this catchment would have a high influence on many dams, particularly on decreased sediment transport, with no advantages for annual water yield

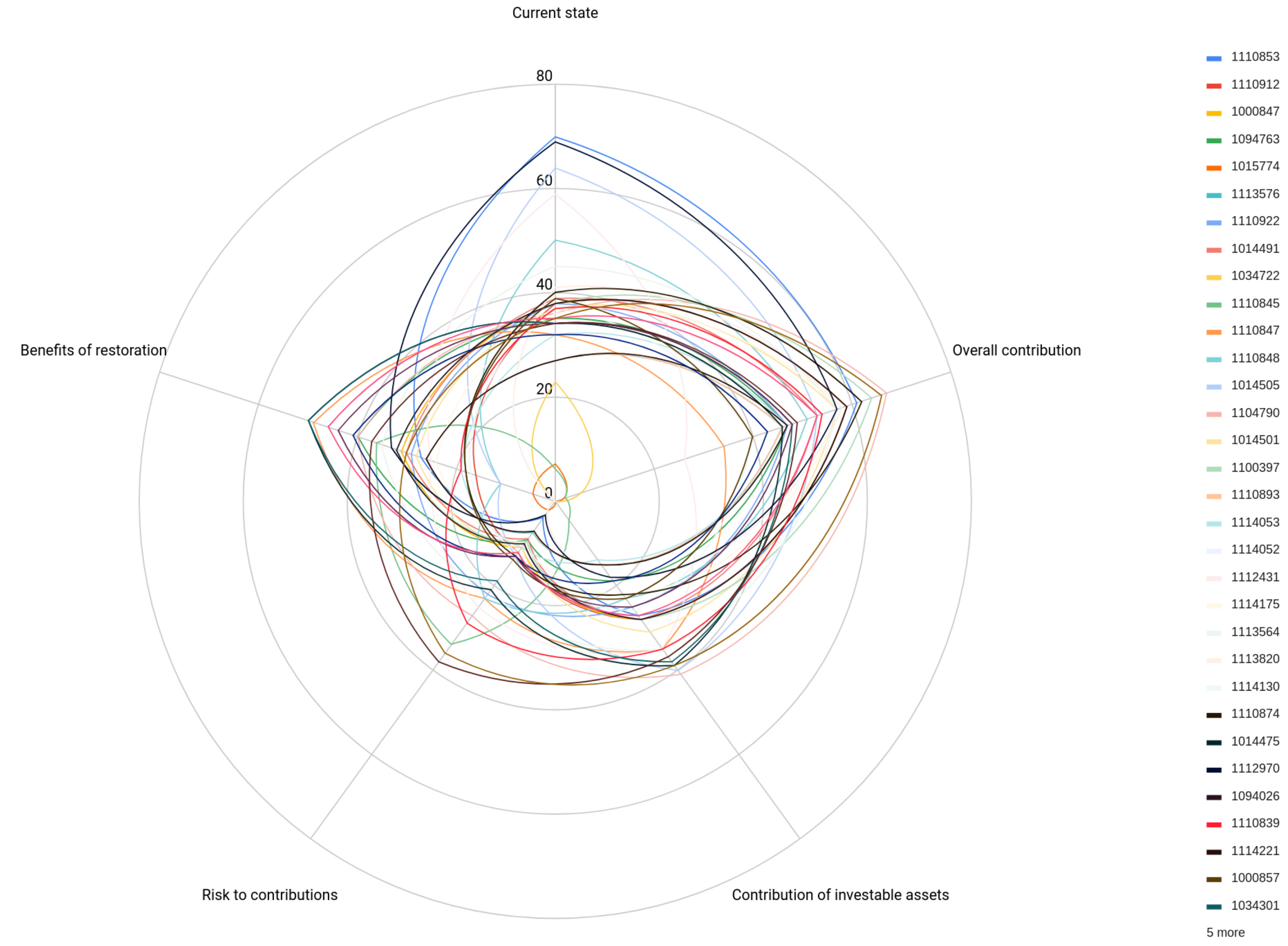


Fig 9 In the Sao Francisco two dam catchment are in good current state with significant contributions from nature and low risk but the remaining are in a poor natural state, still have significant contributions, are at higher risk and would bring significant benefits if restored

Appendix 2 Metrics and their calculation

Output #	Variable	Explanation	Notes/Link to documentation
The current state of influential upstream green infrastructure			
ST1	Upstream protected area (%)	Indicates the proportion of the upstream area under protected area status.	Protected areas from WDPA, flowlines based on HydroSHEDS. All datasets listed under prepare data under prepare data here
ST2	Upstream semi-natural area (%)	Indicates the proportion of the upstream area not under human land use	Human land uses include cropland, pasture, built up, mining, oil and gas, roads. All datasets listed under prepare data here
ST3	Upstream forest area (%)	Indicates the proportion of the upstream area under forest	All datasets listed under prepare data under prepare data here
The overall contribution of upstream nature to dam operation			
CO1	Annual water provision by semi-natural areas (% of total)	Indicates percentage of annual water input to dam that derives from all green infrastructure (i.e. not human intervened land)	Human land uses include cropland, pasture, built up, mining, oil and gas, roads. All datasets listed under prepare data here. Water balance calculated by WaterWorld, documented here
CO2	Maximum monthly water provision by semi-natural areas (% of total)	Indicates maximum monthly (usually dry season) water input to dam that derives from all green infrastructure (i.e. not human intervened land)	Human land uses include cropland, pasture, built up, mining, oil and gas, roads. All datasets listed under prepare data here. Water balance calculated by WaterWorld, documented here
CO3	Upstream sediment retention (deposition) by semi-natural areas (% of total)	Indicates percentage of annual sediment input to dam that derives from all green infrastructure (i.e. not human intervened land)	Calculated by WW sediment module, documented here. All datasets listed under prepare data under prepare data here

CO4	Annual water quantity from fog interception (% of total)	Indicates percentage of annual total water input that derives from fog interception by cloud-affected forest	Calculated by WW fog module, documented here. All datasets listed under prepare data under prepare data here
CO5	Monthly maximum water quantity from fog interception (% of total)	Indicates maximum monthly (usually dry season) percentage of annual total water input that derives from fog interception by cloud-affected forest in the dry-season	Calculated by WW fog module, documented here. All datasets listed under prepare data under prepare data here
The contribution of specific investable natural assets to dam operation			
AS1	Hydrological influence of upstream protected areas (%)	Indicates the annual average hydrological influence of upstream protected areas on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here
AS2	Monthly maximum hydrological influence of upstream protected areas (%)	Indicates the monthly maximum (usually dry season) hydrological influence of upstream protected areas on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here
AS3	Hydrological influence of unprotected upstream non-forest, semi-natural areas (%)	Indicates the annual average hydrological influence of upstream unprotected non-forest, natural areas on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here All datasets listed under prepare data under prepare data here
AS4	Monthly maximum hydrological influence of upstream, unprotected non-forest, semi-natural areas (%)	Indicates the maximum monthly (usually dry season) hydrological influence of upstream unprotected non-forest, natural areas on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here All datasets listed under prepare data under prepare data here
AS5	Hydrological influence of upstream unprotected forests	Indicates the annual average hydrological influence of upstream unprotected forests on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here All datasets listed under prepare data under prepare data here

	(%)		
AS6	Monthly maximum hydrological influence of upstream unprotected forests (%)	Indicates the monthly maximum (usual dry season) hydrological influence of upstream forests on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here All datasets listed under prepare data under prepare data here
AS7	Hydrological influence of upstream cloud-affected forests (%)	Indicates the annual average hydrological influence of upstream cloud forests on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here All datasets listed under prepare data under prepare data here
AS8	Monthly maximum hydrological influence of upstream cloud-affected forests (%)	Indicates the monthly maximum (usually dry season) hydrological influence of upstream cloud forests on inputs to the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here.
The current and future risk of upstream land use change to dam operation			
RI1	Current human footprint on water quality (%)	Indicates the annual average potential pollution footprint of human land uses on inputs to the dam	Uses WW Human footprint on water quality metric, documented here All datasets listed under prepare data under prepare data here.
RI2	Hydrological influence of recent upstream deforestation (% of inputs)	Indicates the annual average hydrological influence of recent deforestation upstream of the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. . Recent refers to last 20 years
RI3	Hydrological influence of recent upstream afforestation (% of inputs)	Indicates the annual average hydrological influence of recent afforestation upstream of the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. Recent refers to last 20 years

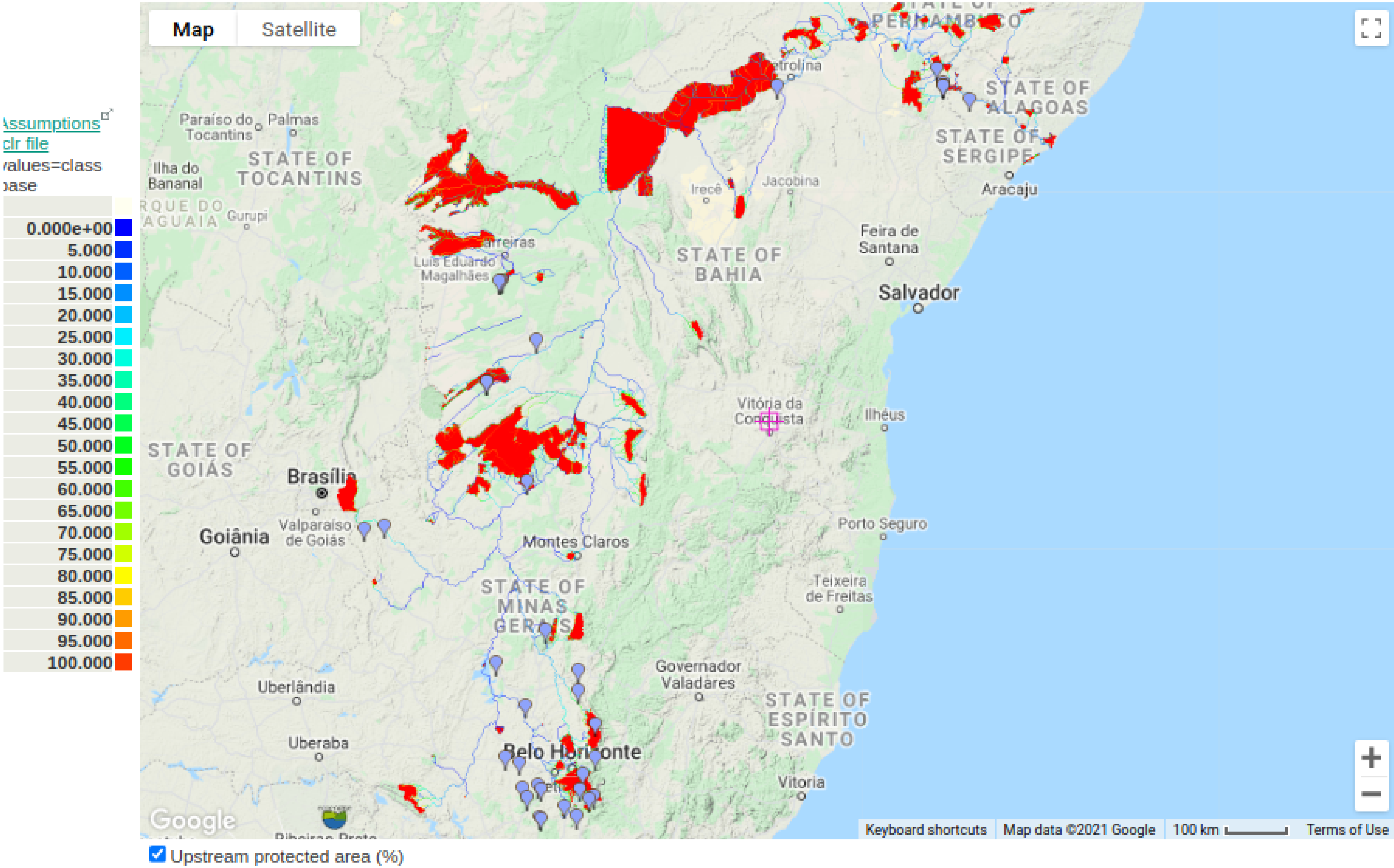
RI4	Hydrological influence of all upstream intervened land (% of inputs)	Indicates the annual average hydrological influence of intervened land upstream of the dam	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. Intervened land refers to all human land uses: cropland, pasture, built up, mining, oil and gas, roads.
RI5	Monthly maximum hydrological influence of all upstream intervened land (% of inputs)	Indicates the monthly maximum (usually dry season) hydrological influence of deforestation projected for the next 30 years based on recently observed rates	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RI6	Hydrological influence of upstream 'defor' deforestation scenario (% of inputs)	Indicates the annual average hydrological influence of deforested areas for the deforestation scenario applied	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RI7	Decrease in water yield due to upstream 'defor' deforestation scenario (%)	Indicates the annual average simulated decrease in water yield for the deforestation scenario applied	Water yield calculated by WaterWorld as described here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RI8	Maximum monthly decrease in water yield due to upstream 'defor' deforestation scenario (%)	Indicates the monthly maximum (usually dry-season) simulated decrease in water yield for the deforestation scenario applied	Water yield calculated by WaterWorld as described here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RI9	Increase in sediment transport due to upstream 'defor' deforestation scenario (%)	Indicates the simulated increases in sediment transport to the dam for the deforestation scenario applied	Calculated by WW sediment module, documented here. All datasets listed under prepare data under prepare data here The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
The magnitude of beneficial outcomes for the dam of restoration of upstream green infrastructure			

RE1	Hydrological influence of upstream 'refor' restoration scenario (% of inputs)	Indicates the annual average hydrological influence of reforested areas for the restoration scenario applied	Calculated by WW hydrological influence (footprint) metric, documented here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RE2	Increase in water yield due to upstream 'refor' restoration scenario (%)	Indicates annual average increases in water yield for the restoration scenario applied	Water yield calculated by WaterWorld as described here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RE3	Maximum monthly increase in water yield due to upstream 'refor' restoration scenario (%)	Indicates maximum monthly (usually dry season) increases in water yield reforested areas for the restoration scenario applied	Water yield calculated by WaterWorld as described here. All datasets listed under prepare data under prepare data here. The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
RE4	Decrease in sediment transport due to upstream 'refor' restoration scenario (%)	Indicates annual average decreases in sediment transport for the restoration scenario applied	Calculated by WW sediment module, documented here. All datasets listed under prepare data under prepare data here The WW land use change modeller (QUICKLUC) is used to generate the BAU scenario
		Overall priority	
Overall Pri	The overall priority for investment (%)	Combines state, contribution, investment potential, risk and benefits into an overall investment priority (normalised)	All inputs equally weighted, output converted from normalised fraction to per-cent for compatibility with other metrics
GreatestPri	The greatest priority for investing	Defines which of state, contribution, investment potential, risk and benefits is the greatest reason for investment	All inputs equally weighted, output converted from normalised fraction to per-cent for compatibility with other metrics

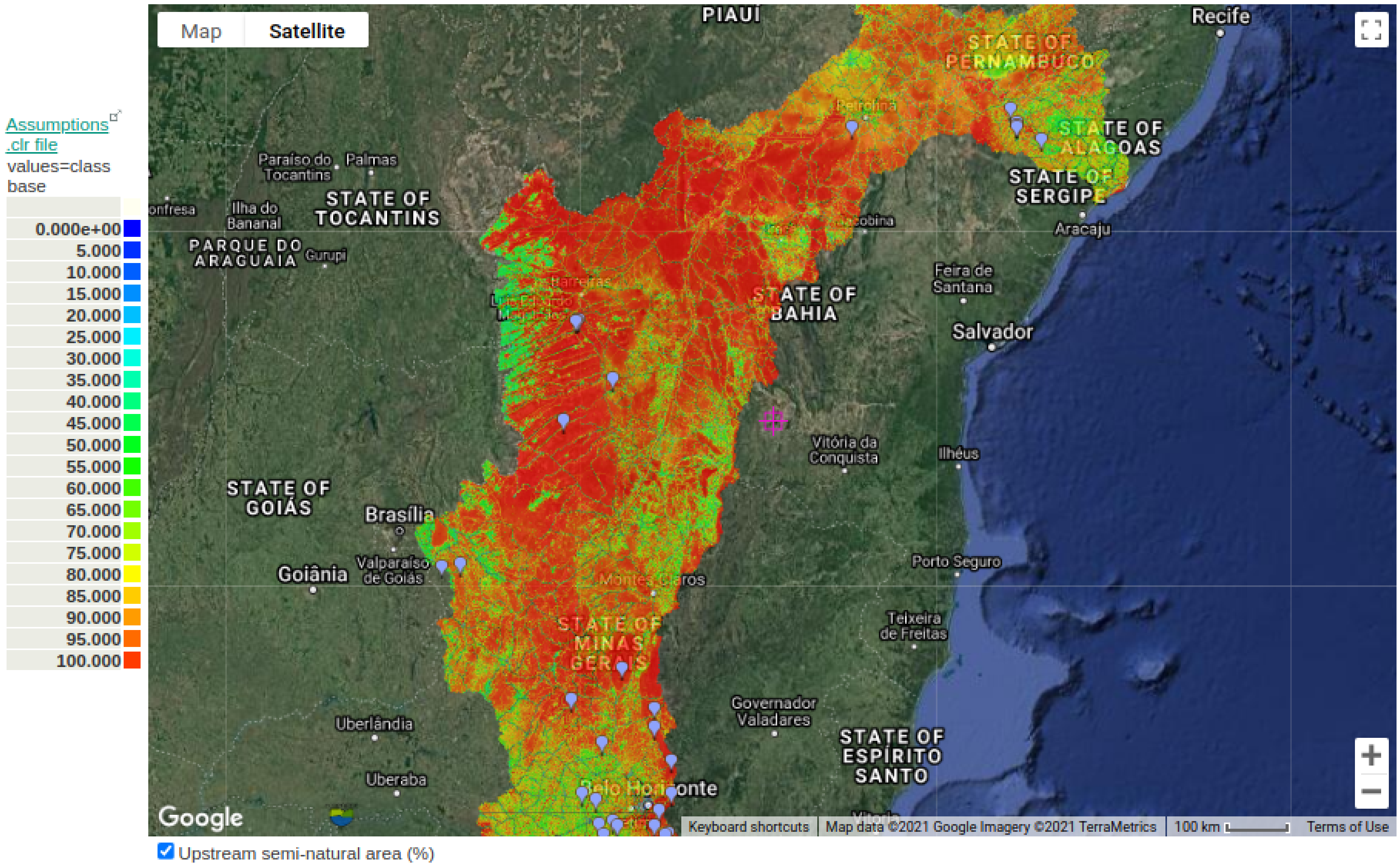
Table 3 Variables used in the Green Infrastructure for Blue Energy (GIBE) Tool in WaterWorld and their meaning.

Appendix 3 Maps

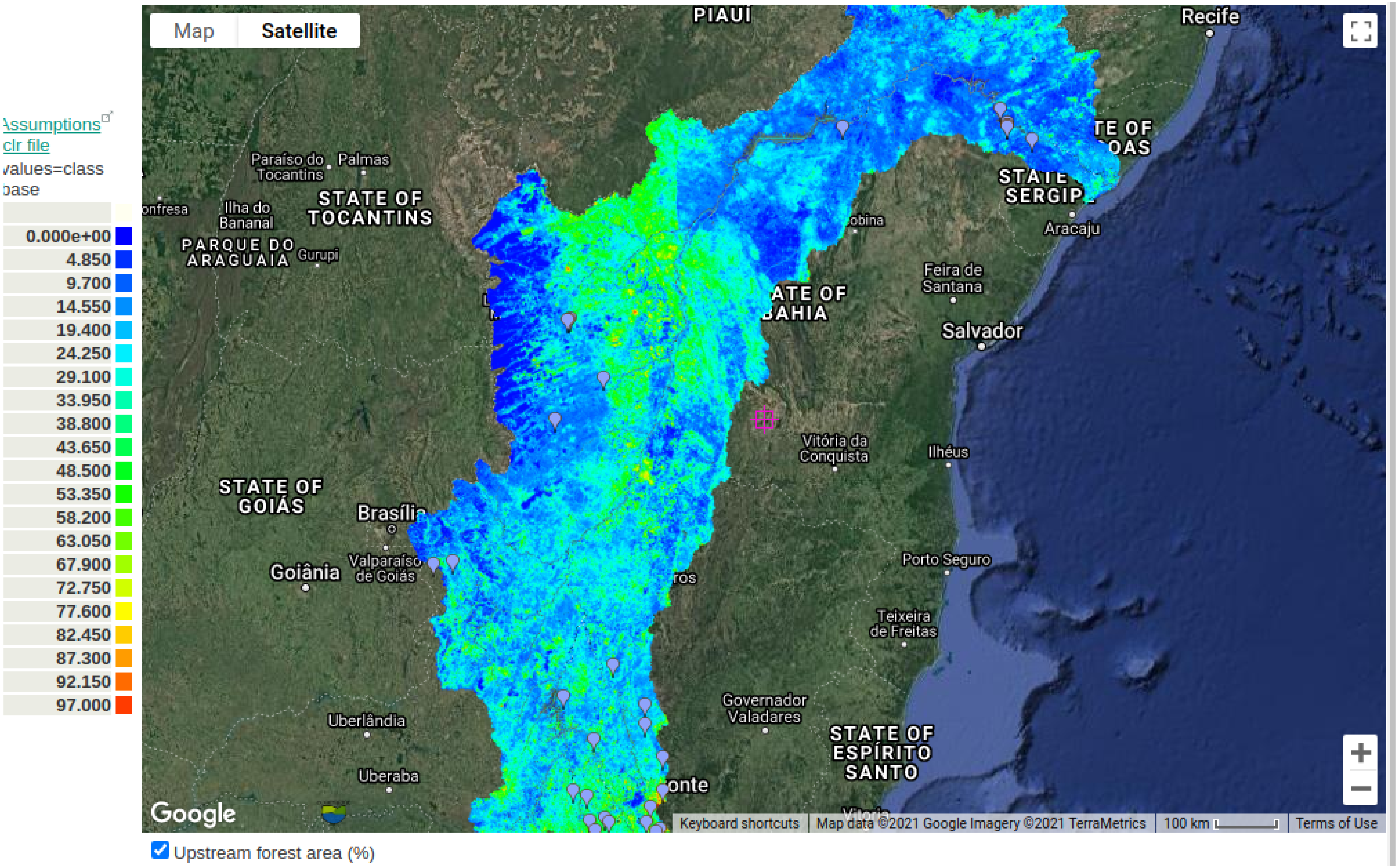
ST1 Upstream protected area (%)



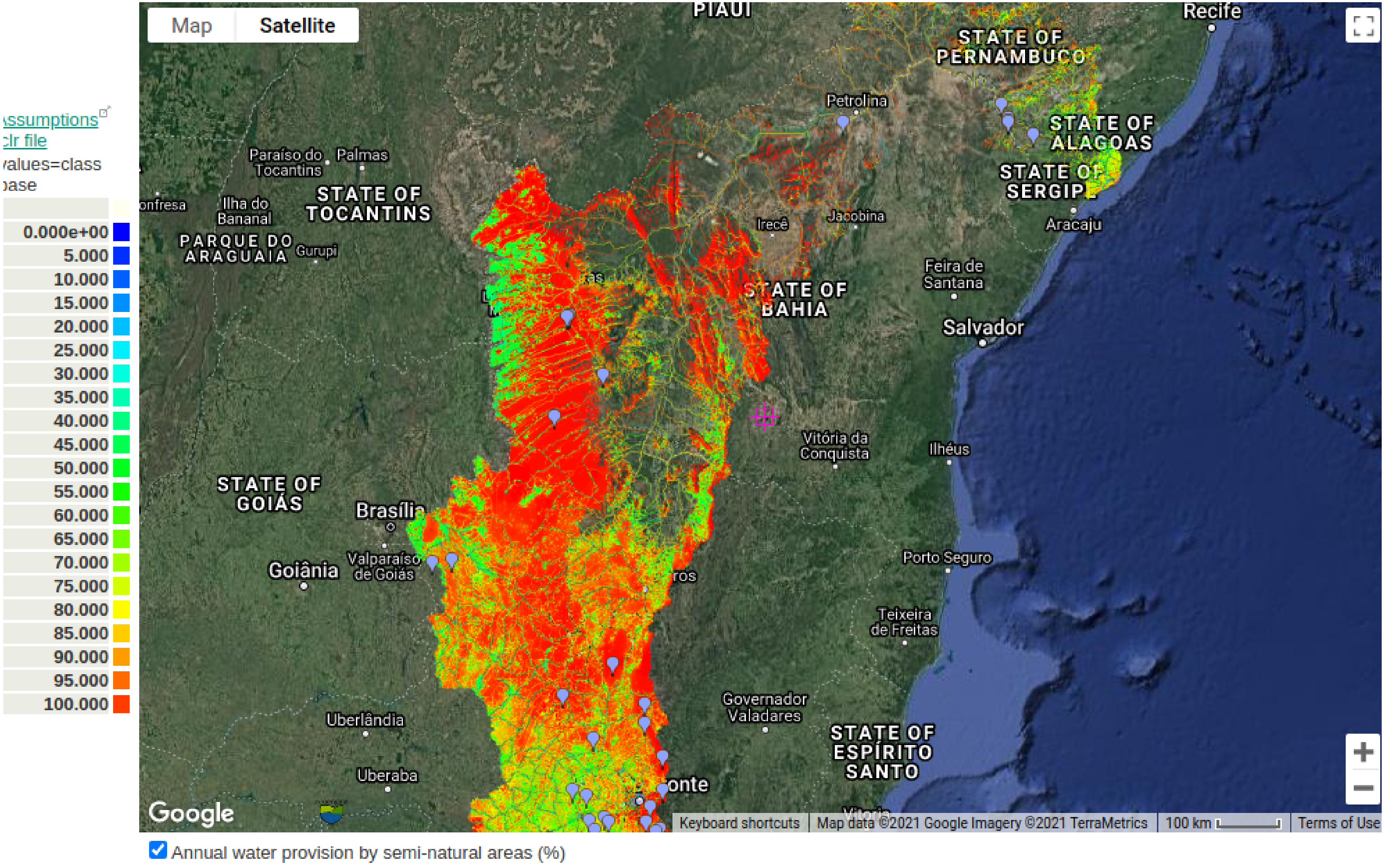
ST2 Upstream semi-natural area (%)



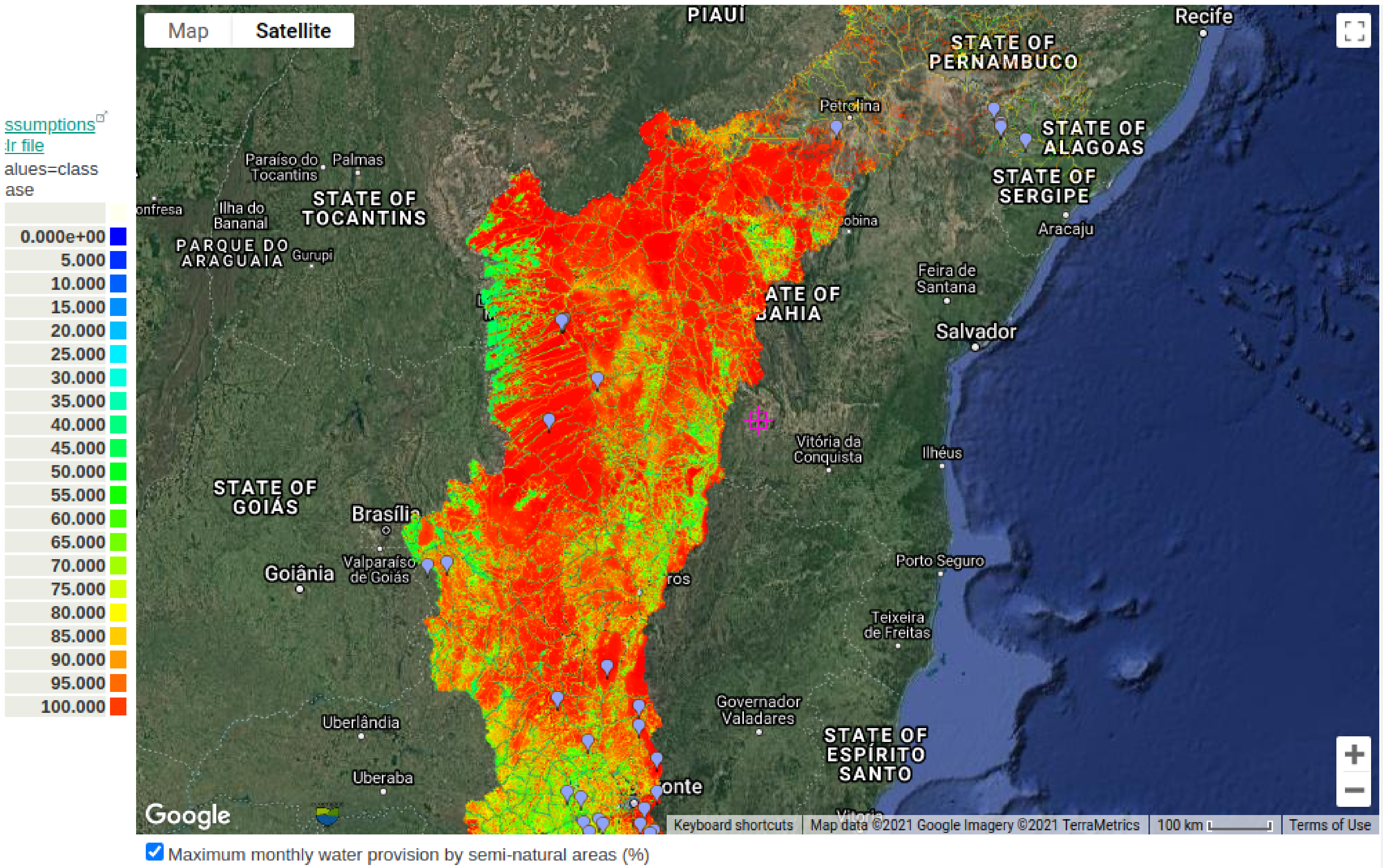
ST3 Upstream forest area (%)



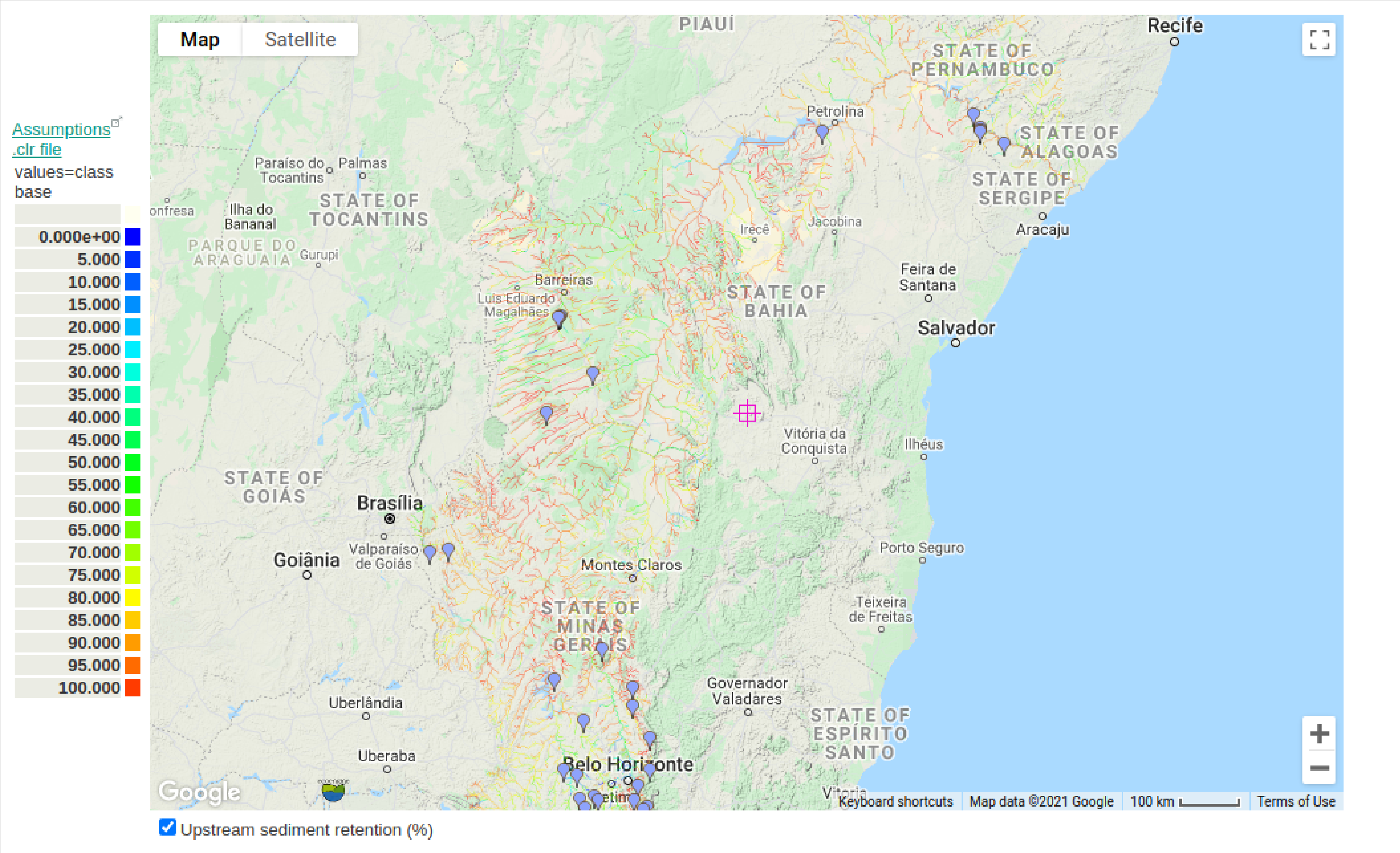
CO1 Annual water provision by semi-natural areas (% of total)



CO2 Maximum monthly water provision by semi-natural areas (% of total)



CO3 Upstream sediment retention (deposition) by semi-natural areas (% of total)



CO4 Annual water quantity from fog interception (% of total)

Assumptions
.clr file
values=class base

0.000e+00	
1.751	
3.502	
5.253	
7.005	
8.756	
10.510	
12.260	
14.010	
15.760	
17.510	
19.260	
21.010	
22.760	
24.520	
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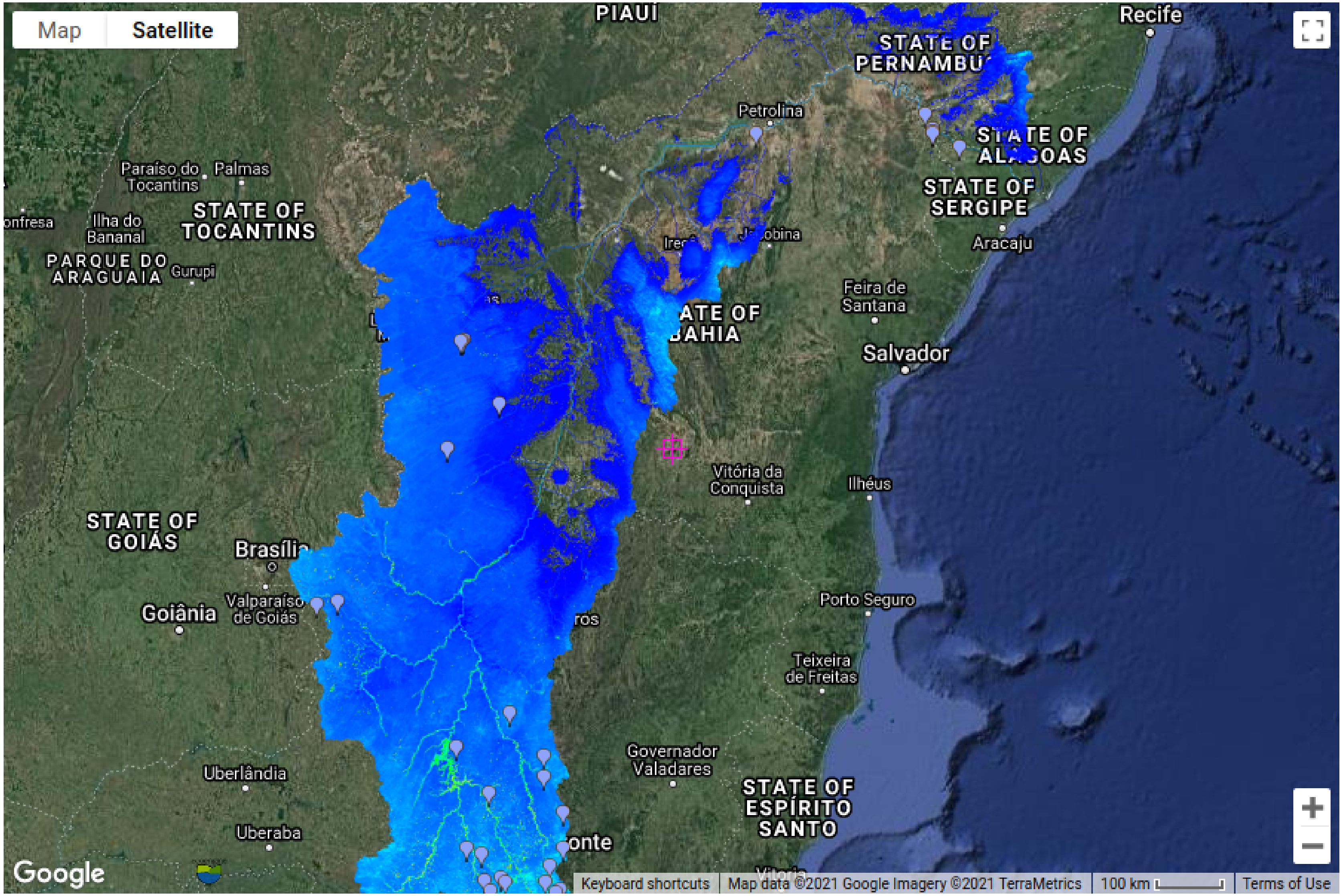
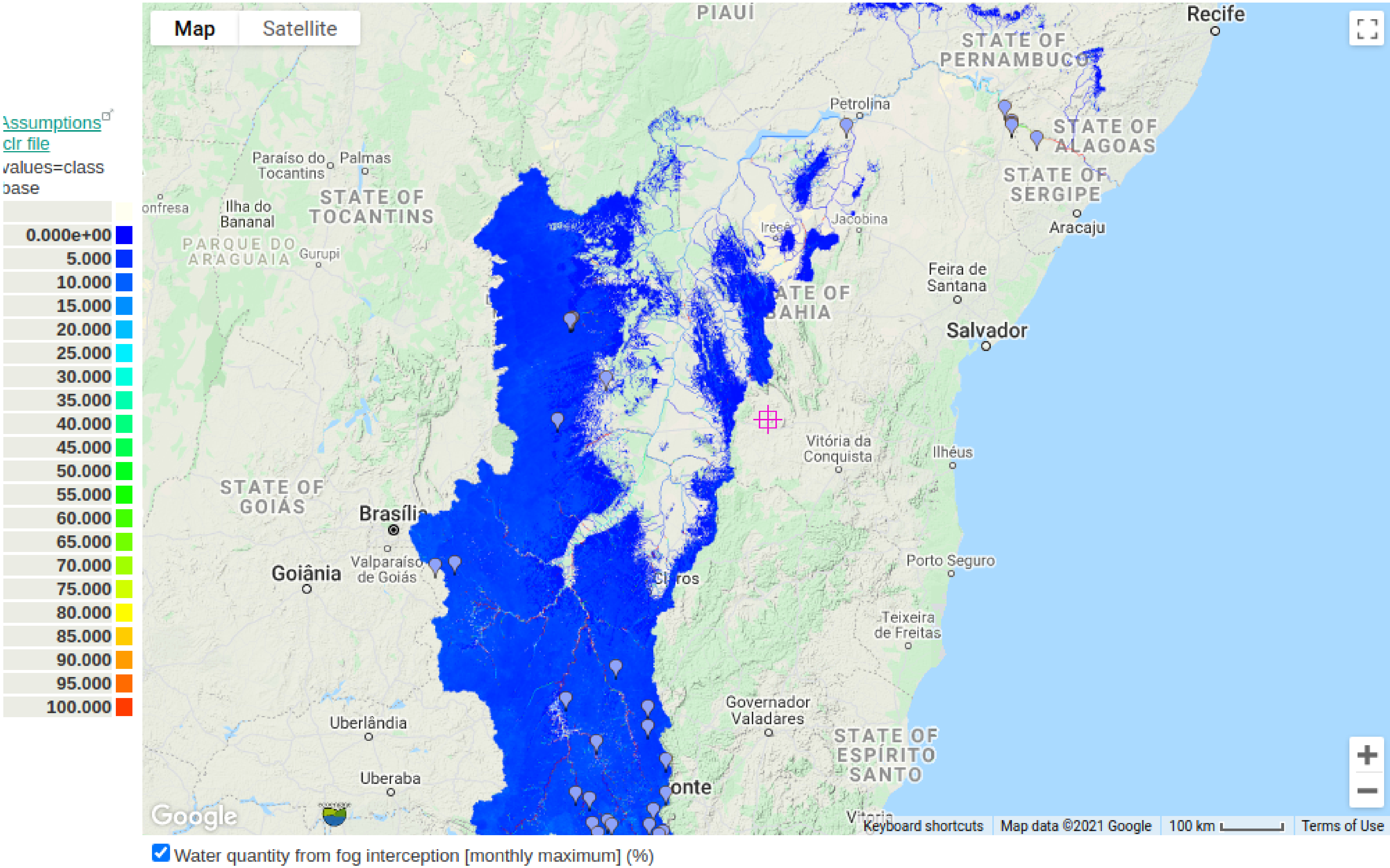
33.270	
35.020	

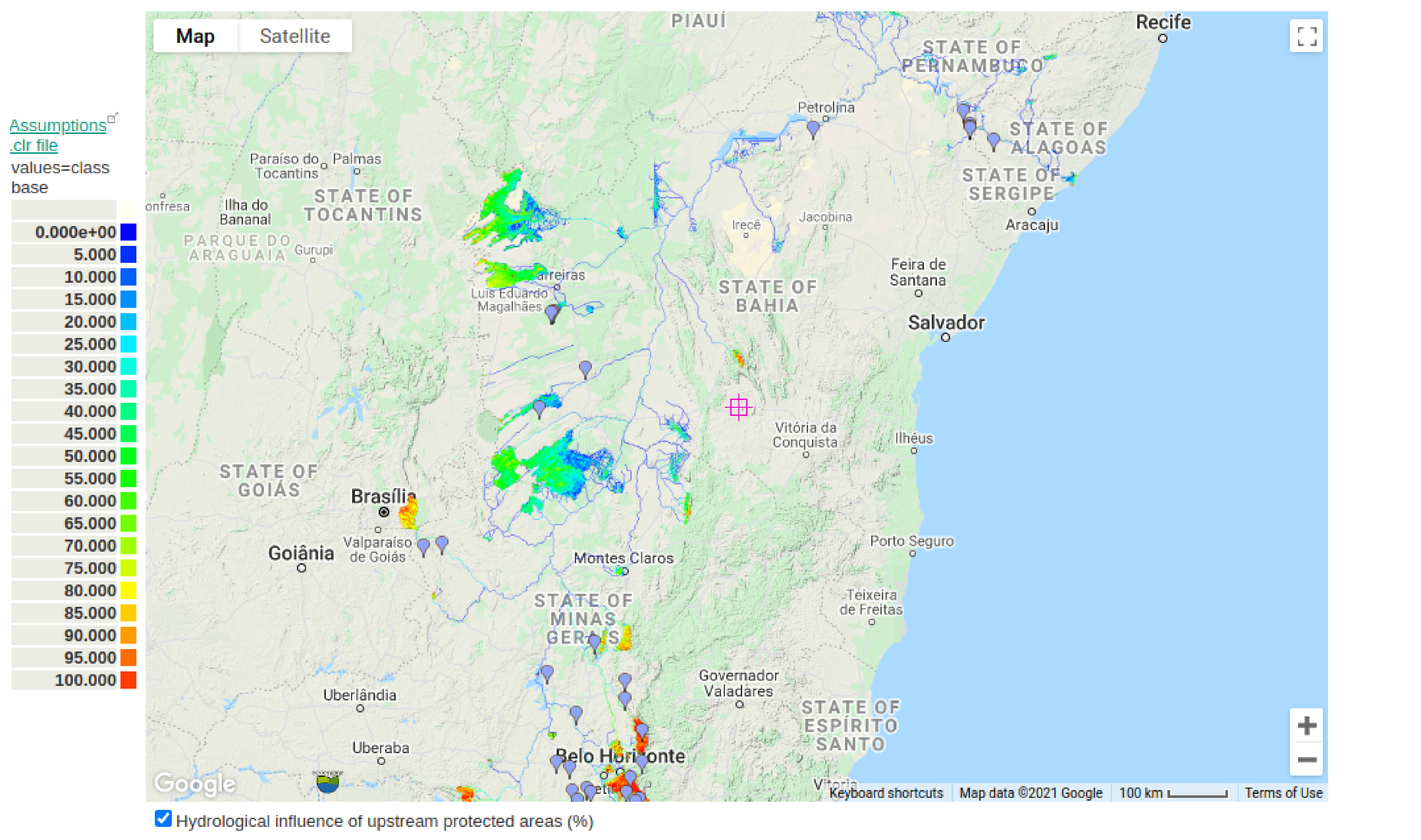


☑ Water quantity from fog interception [annual] (%)

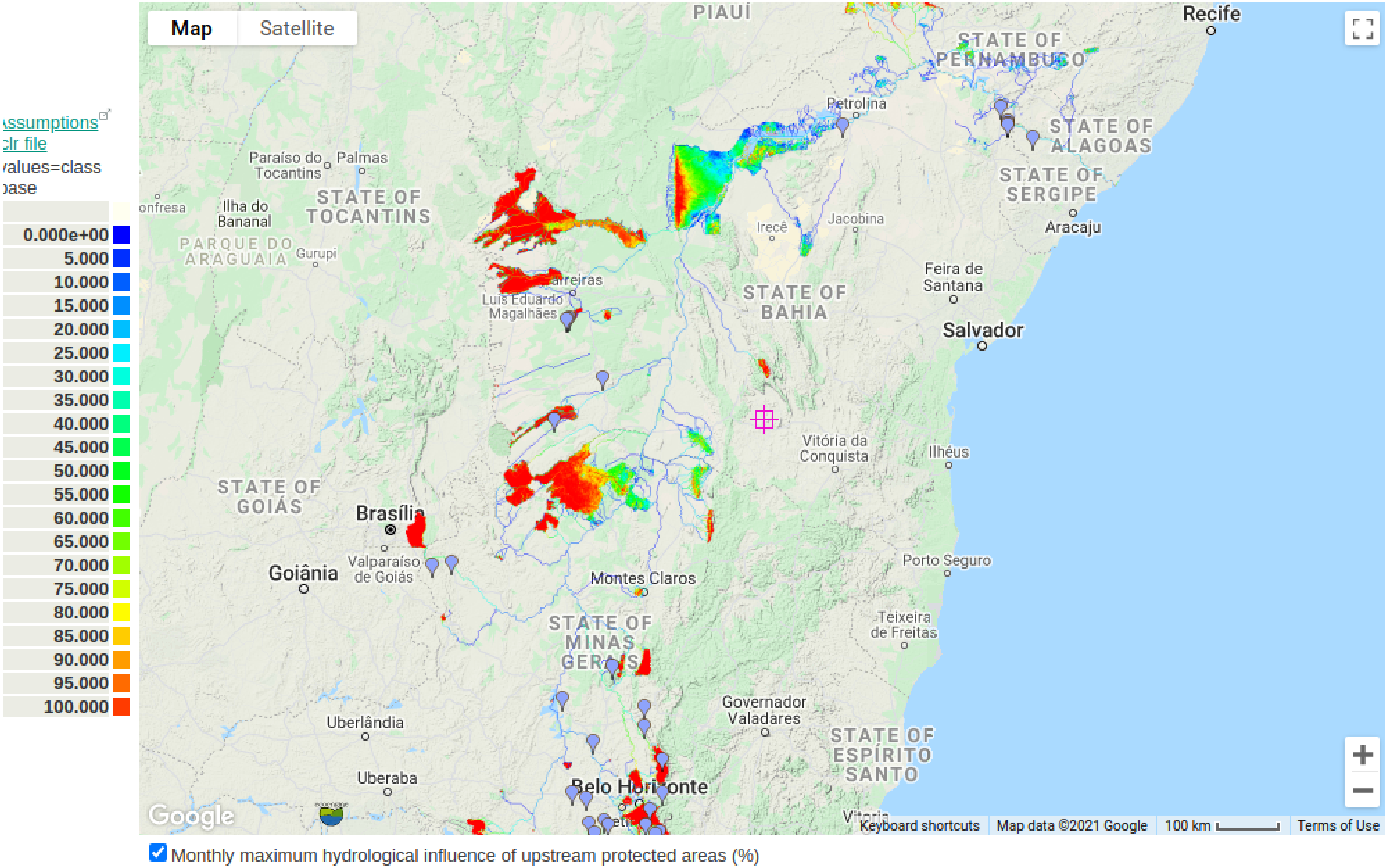
CO5 Monthly maximum water quantity from fog interception (% of total)



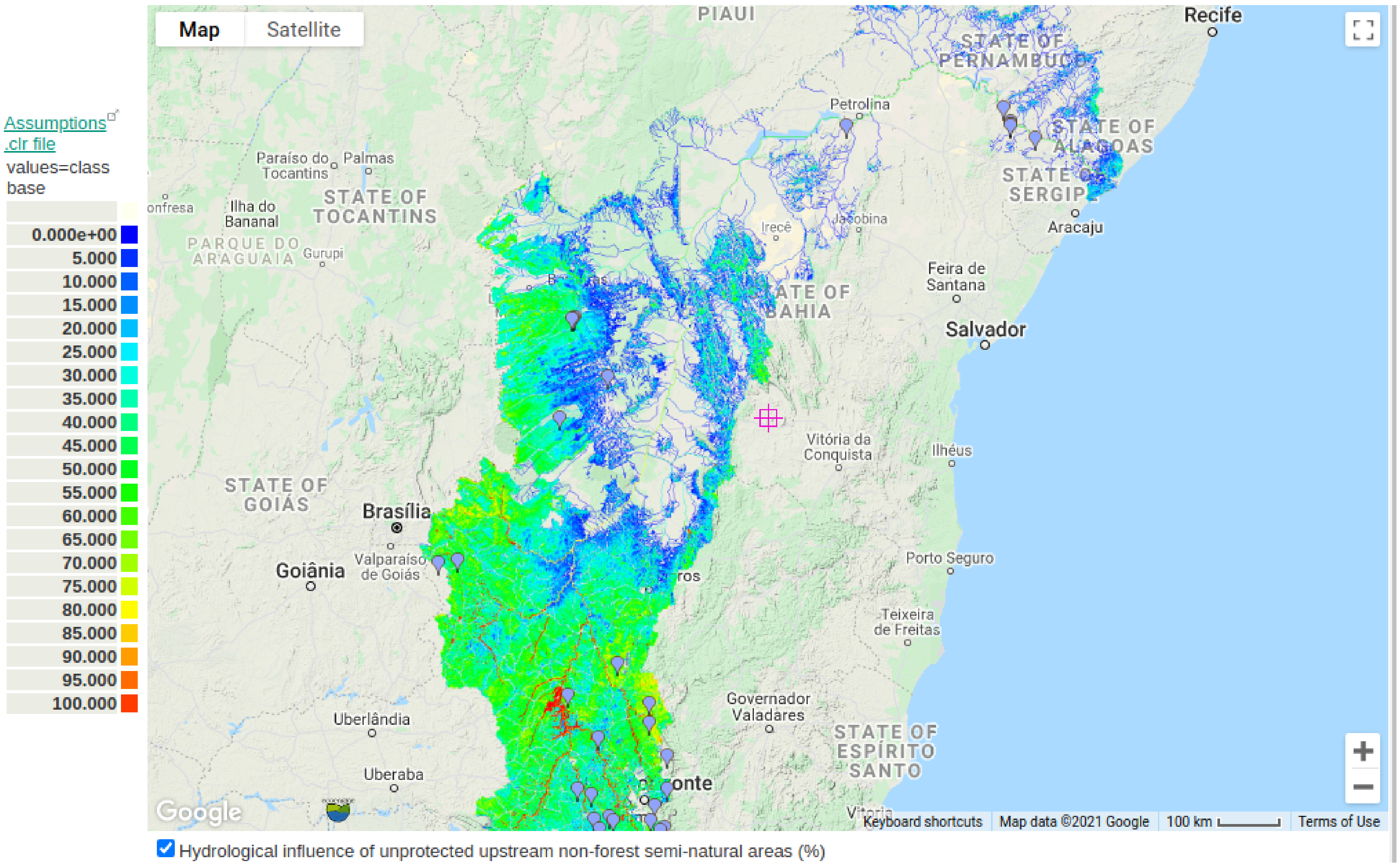
AS1 Hydrological influence of upstream protected areas (%)



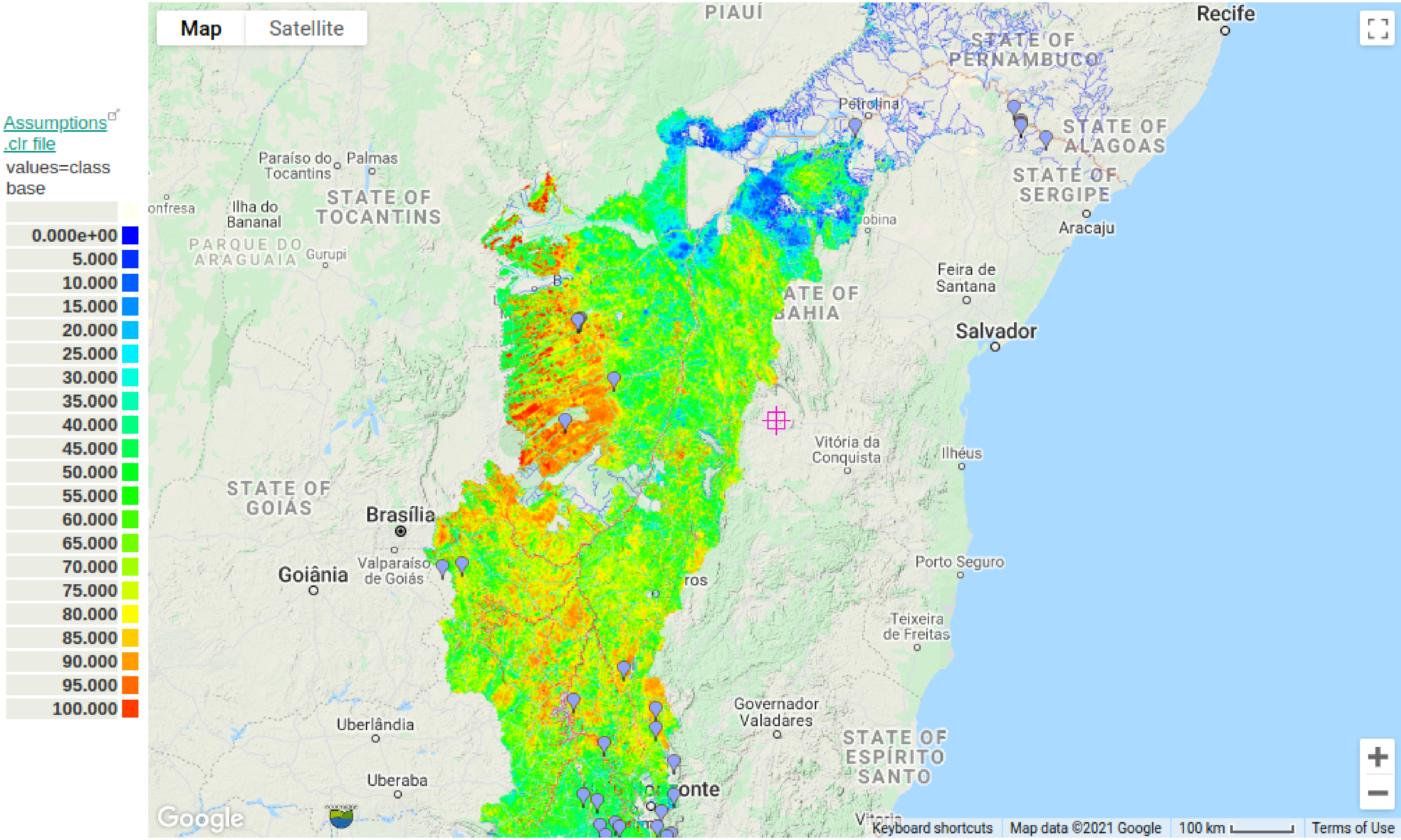
AS2 Monthly maximum hydrological influence of upstream protected areas (%)



AS3 Hydrological influence of unprotected upstream non-forest, semi-natural areas (%)

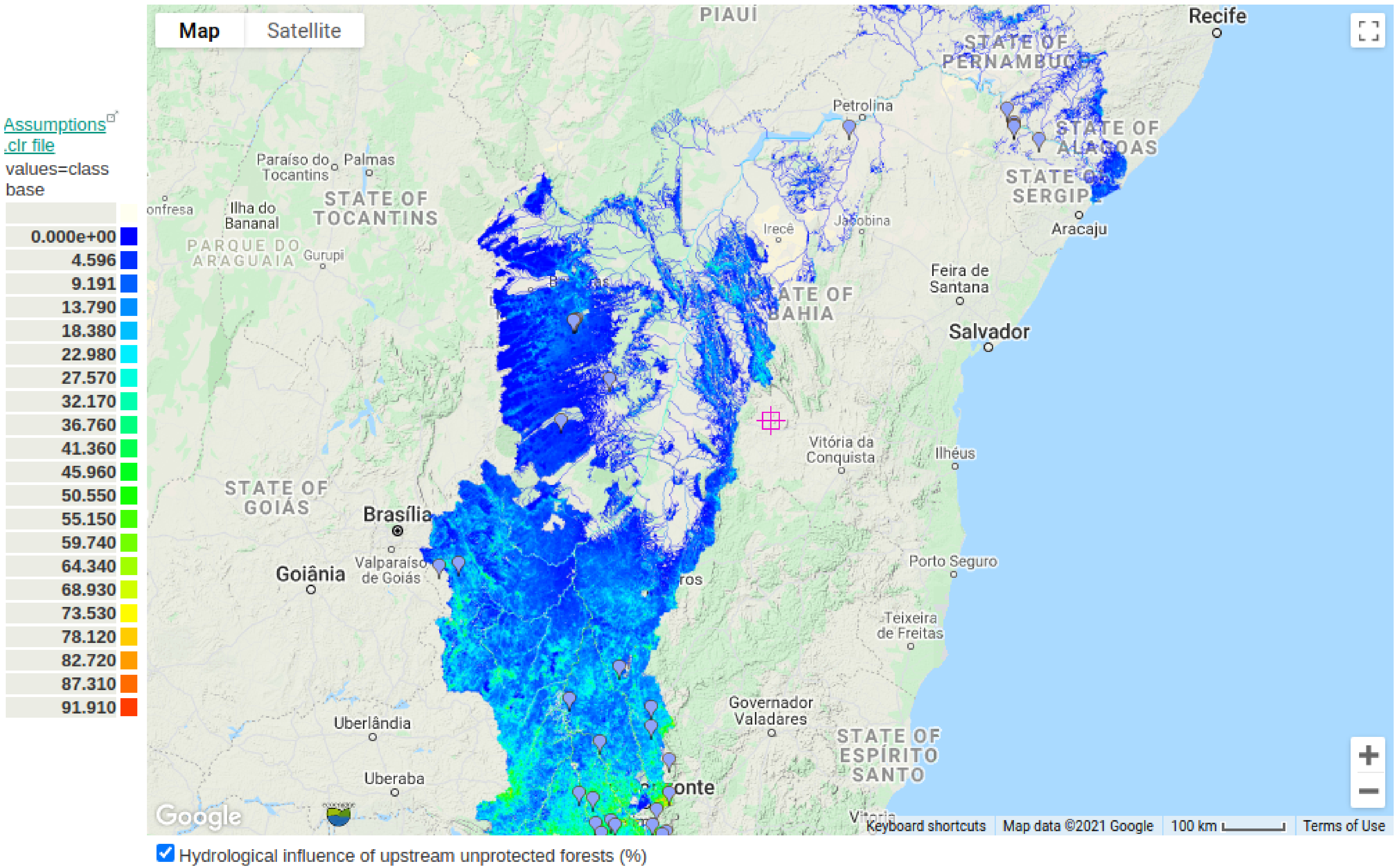


AS4 Monthly maximum hydrological influence of upstream, unprotected non-forest, semi-natural areas (%)

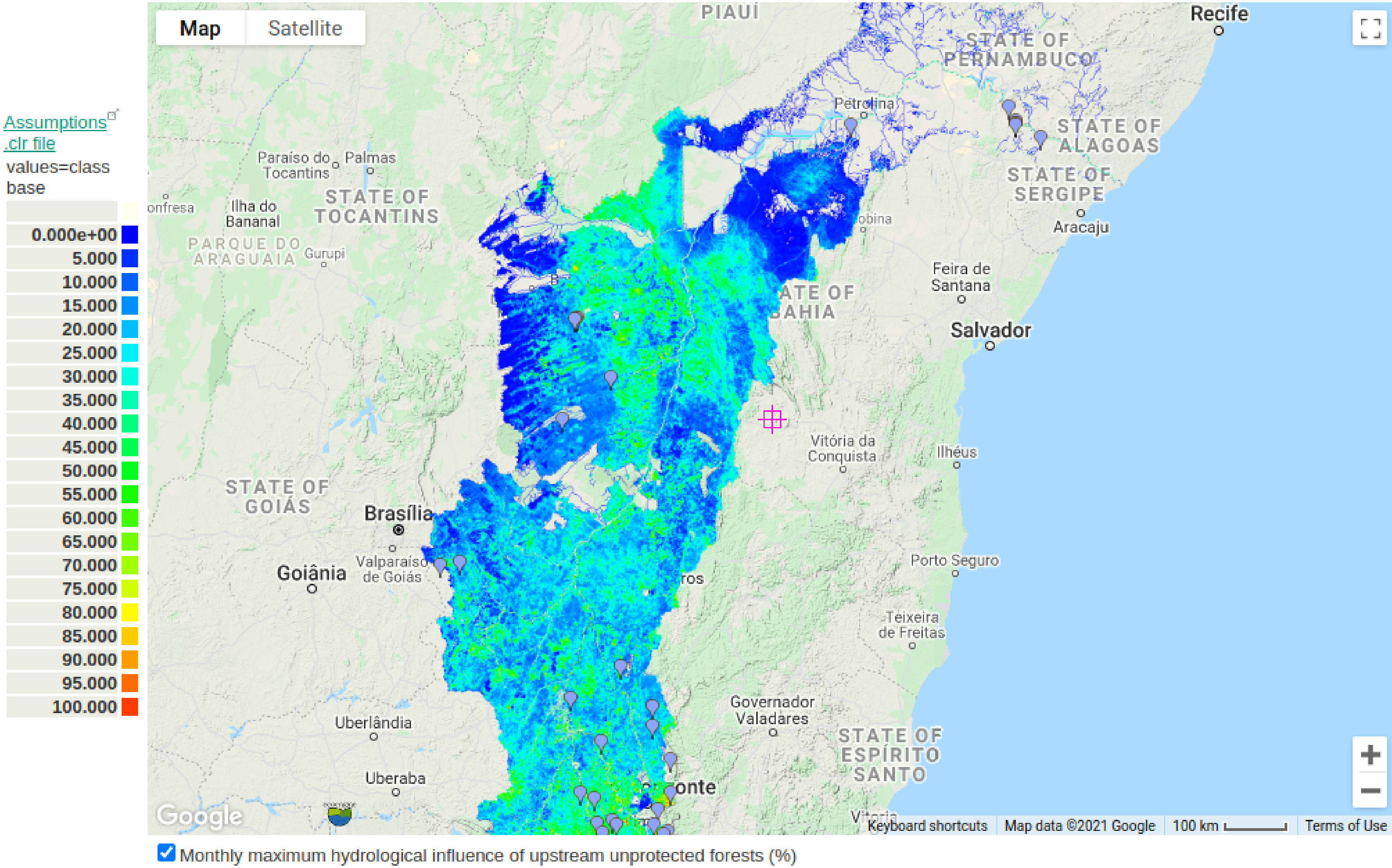


Monthly maximum hydrological influence of upstream, unprotected non-forest semi-natural areas (%)

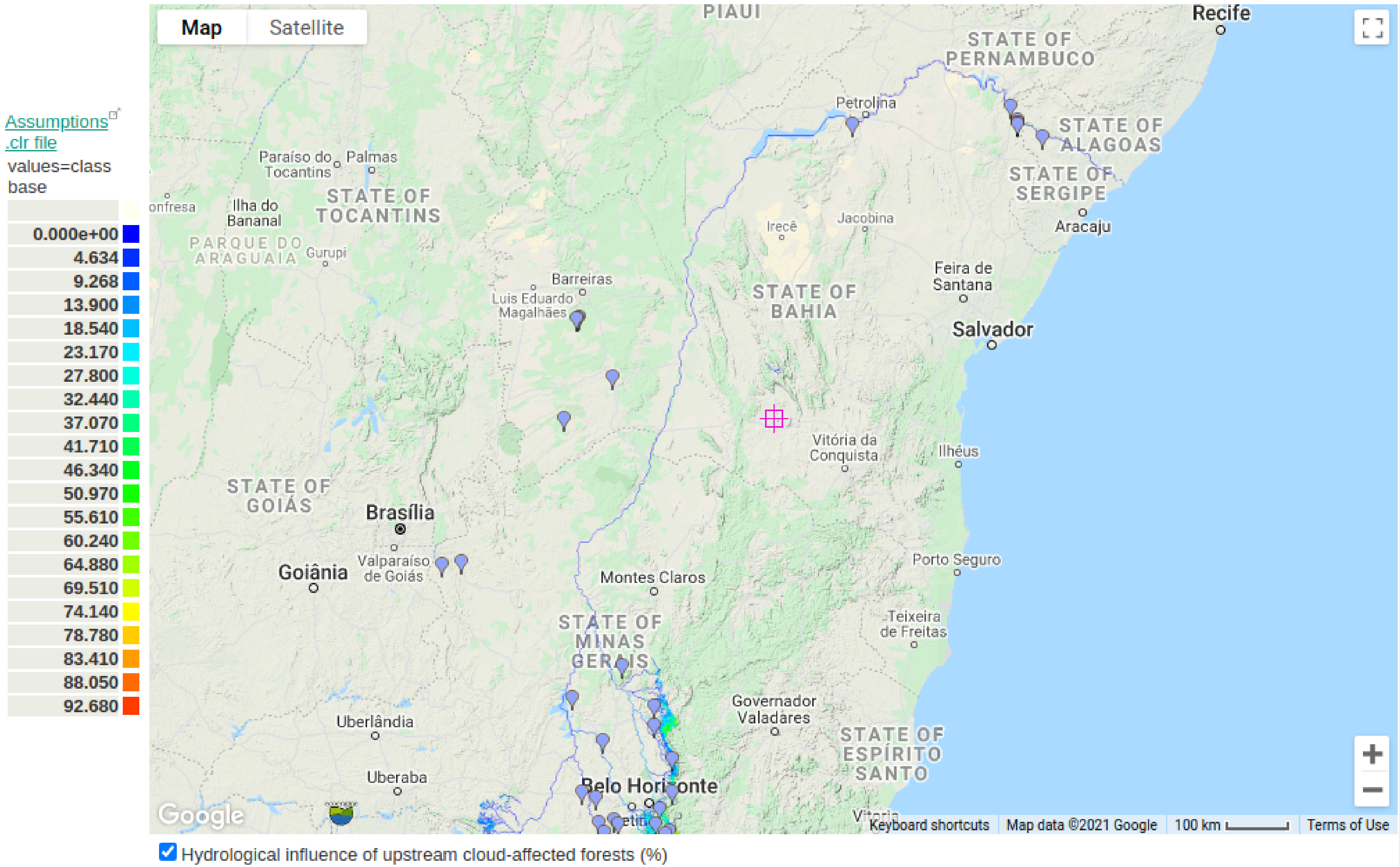
AS5 Hydrological influence of upstream unprotected forests (%)



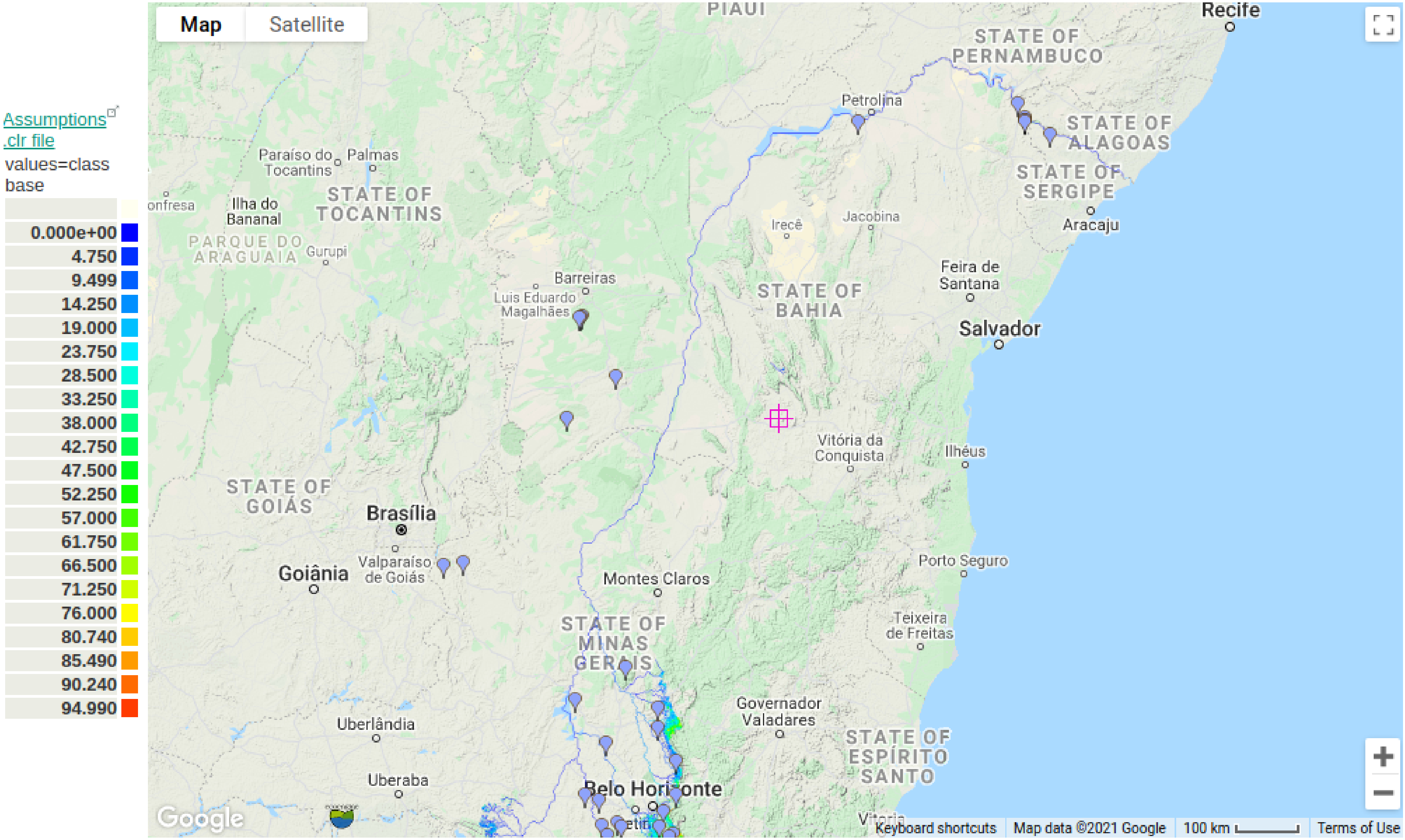
AS6 Monthly maximum hydrological influence of upstream unprotected forests (%)



AS7 Hydrological influence of upstream cloud-affected forests (%)

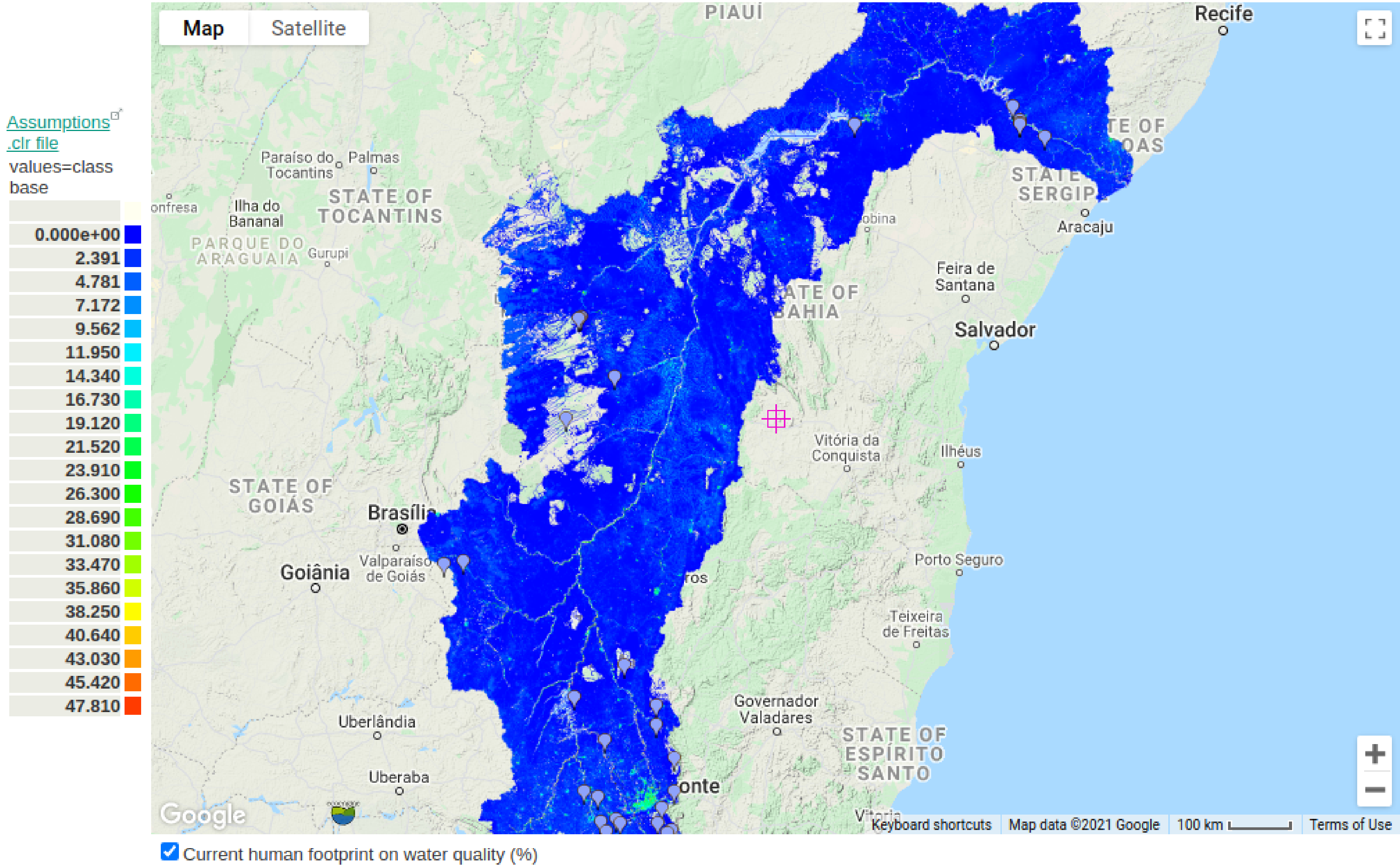


AS8 Monthly maximum hydrological influence of upstream cloud-affected forests (%)

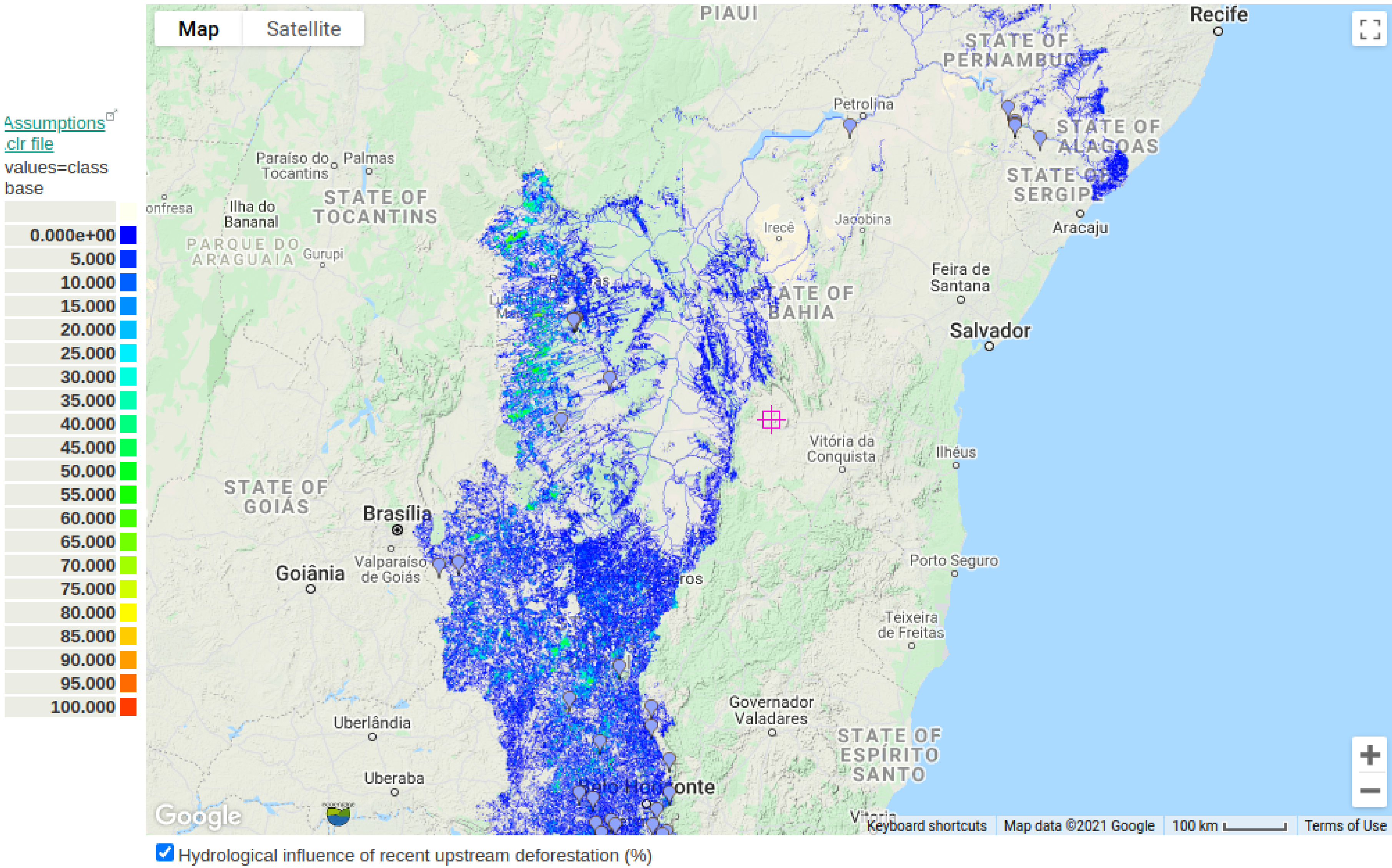


Monthly maximum hydrological influence of upstream cloud-affected forests (%)

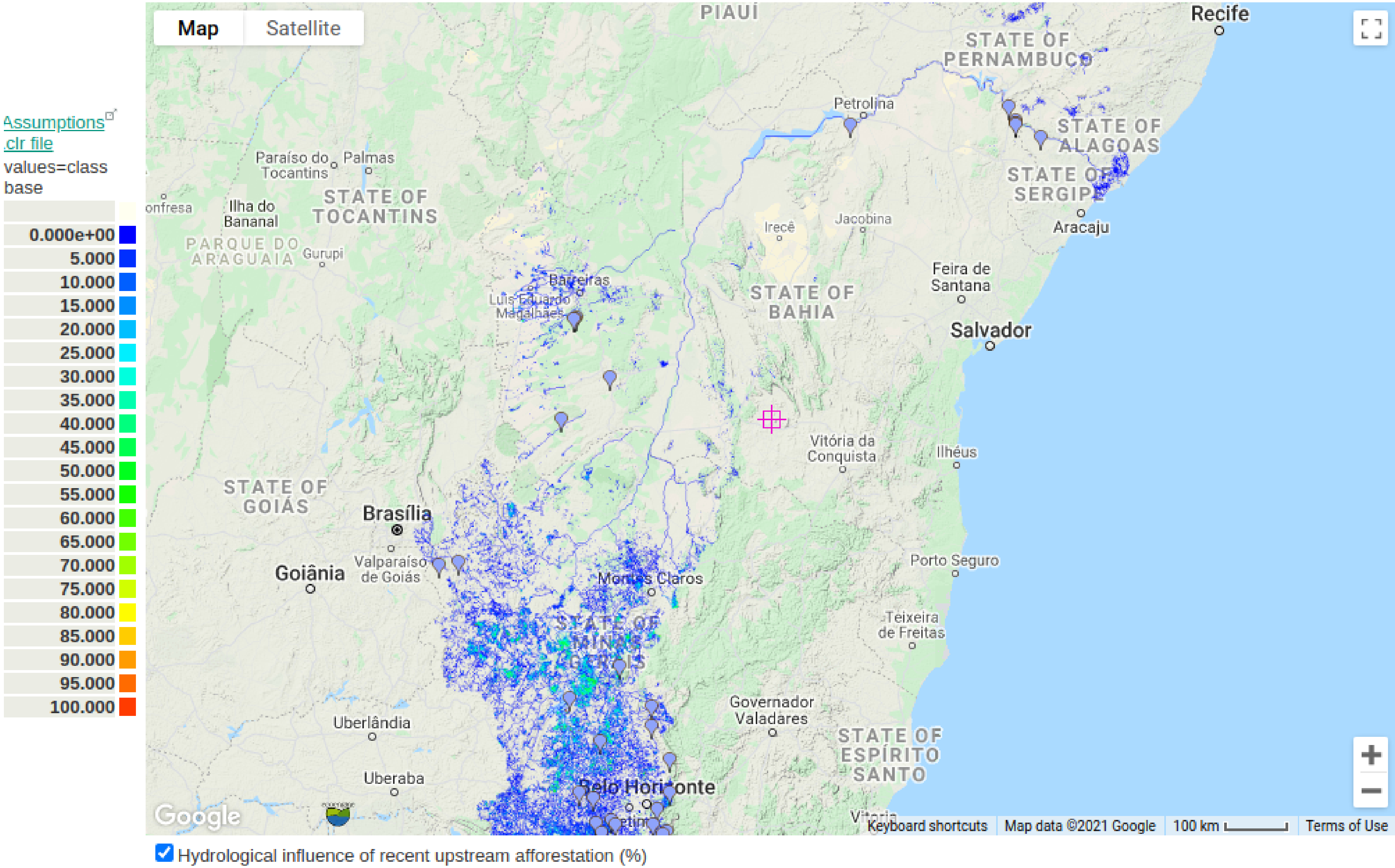
RI1 Current human footprint on water quality (%)



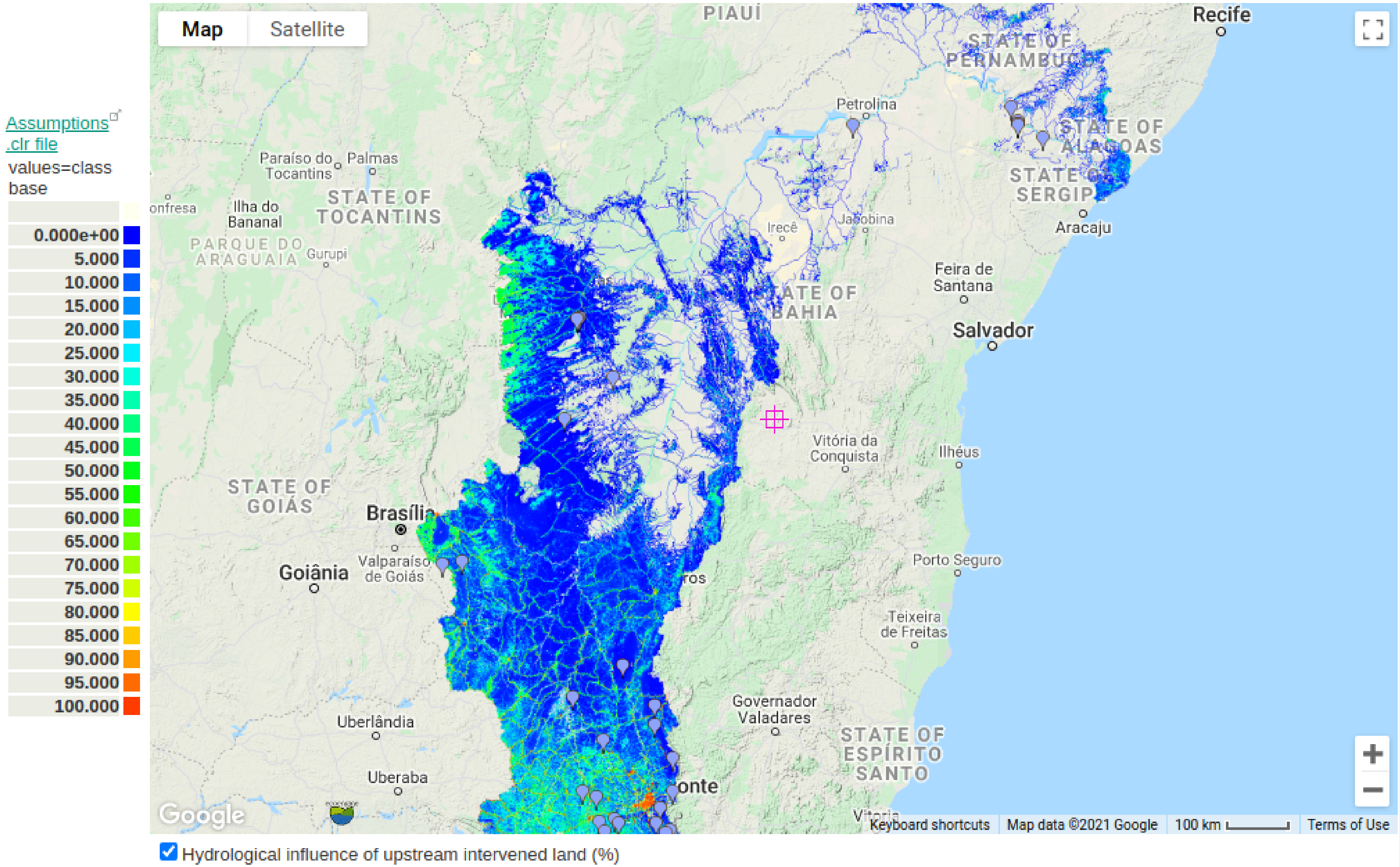
RI2 Hydrological influence of recent upstream deforestation (% of inputs)



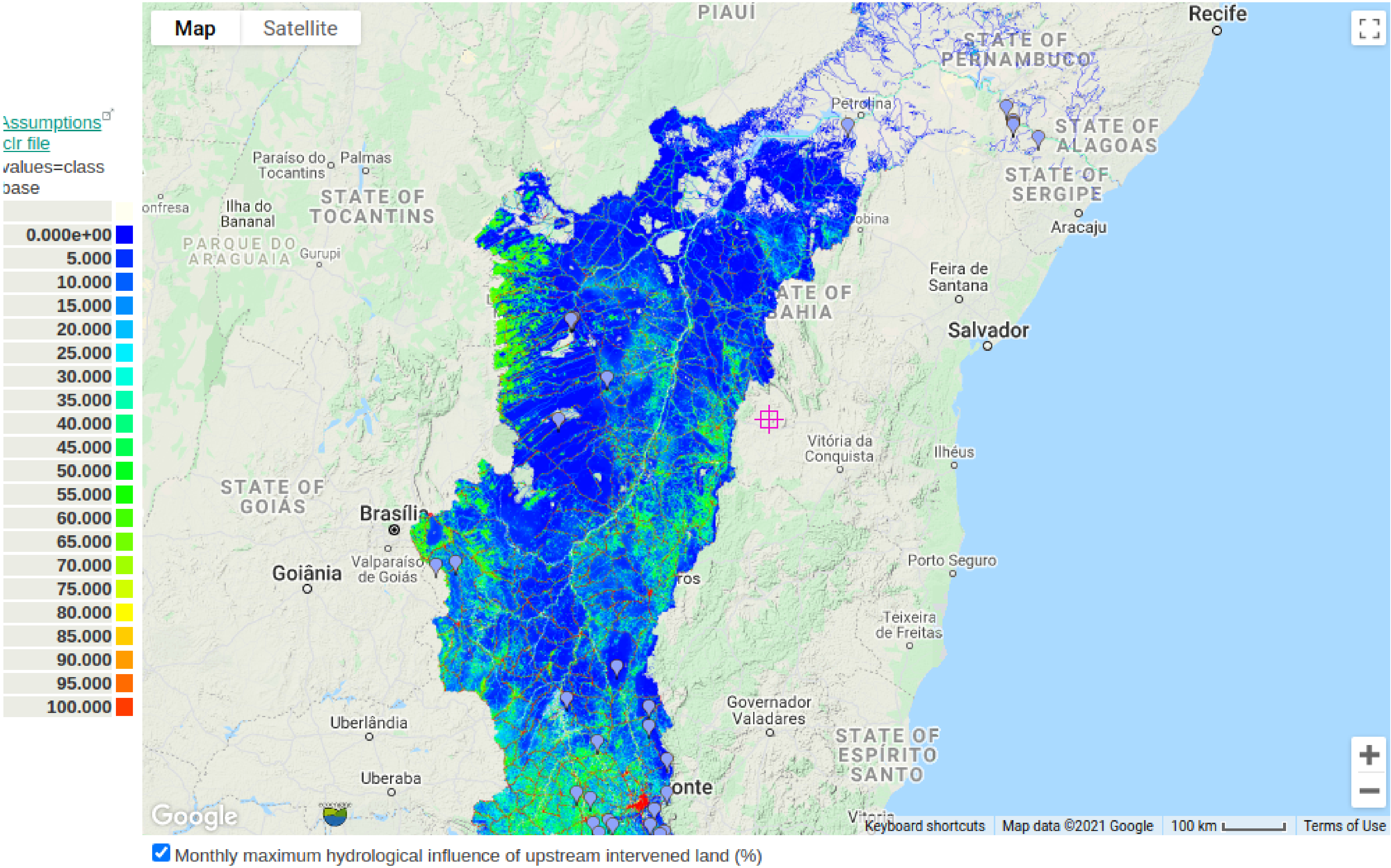
RI3 Hydrological influence of recent upstream afforestation (% of inputs)



RI4 Hydrological influence of all upstream intervened land (% of inputs)



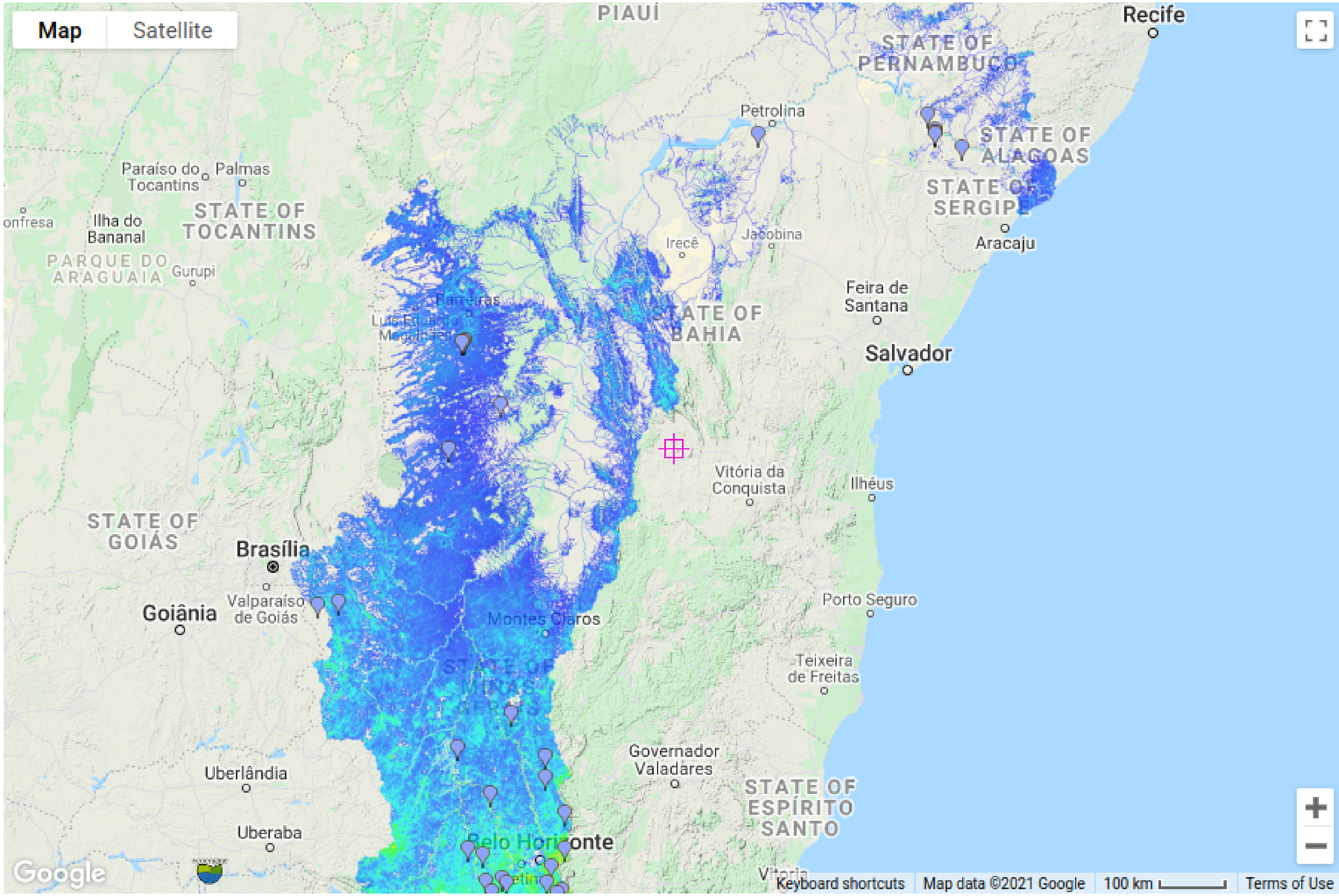
RI5 Monthly maximum hydrological influence of all upstream intervened land (% of inputs)



RI6 Hydrological influence of upstream 'defor' deforestation scenario (% of inputs)

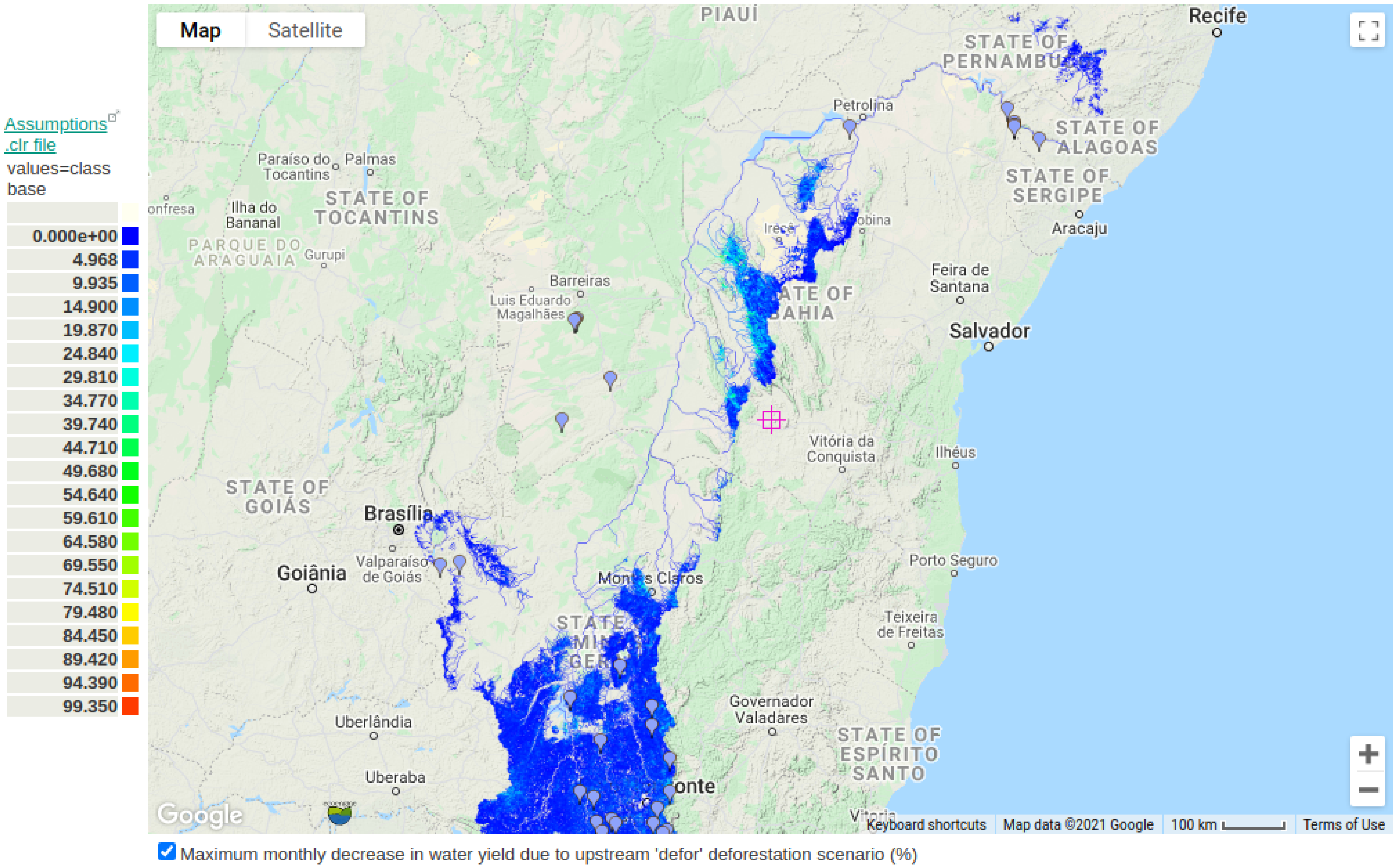
Assumptions
.clr file
values=class base

0.000e+00	
4.901	
9.801	
14.700	
19.600	
24.500	
29.400	
34.300	
39.210	
44.110	
49.010	
53.910	
58.810	
63.710	
68.610	
73.510	
78.410	
83.310	
88.210	
93.110	
98.010	

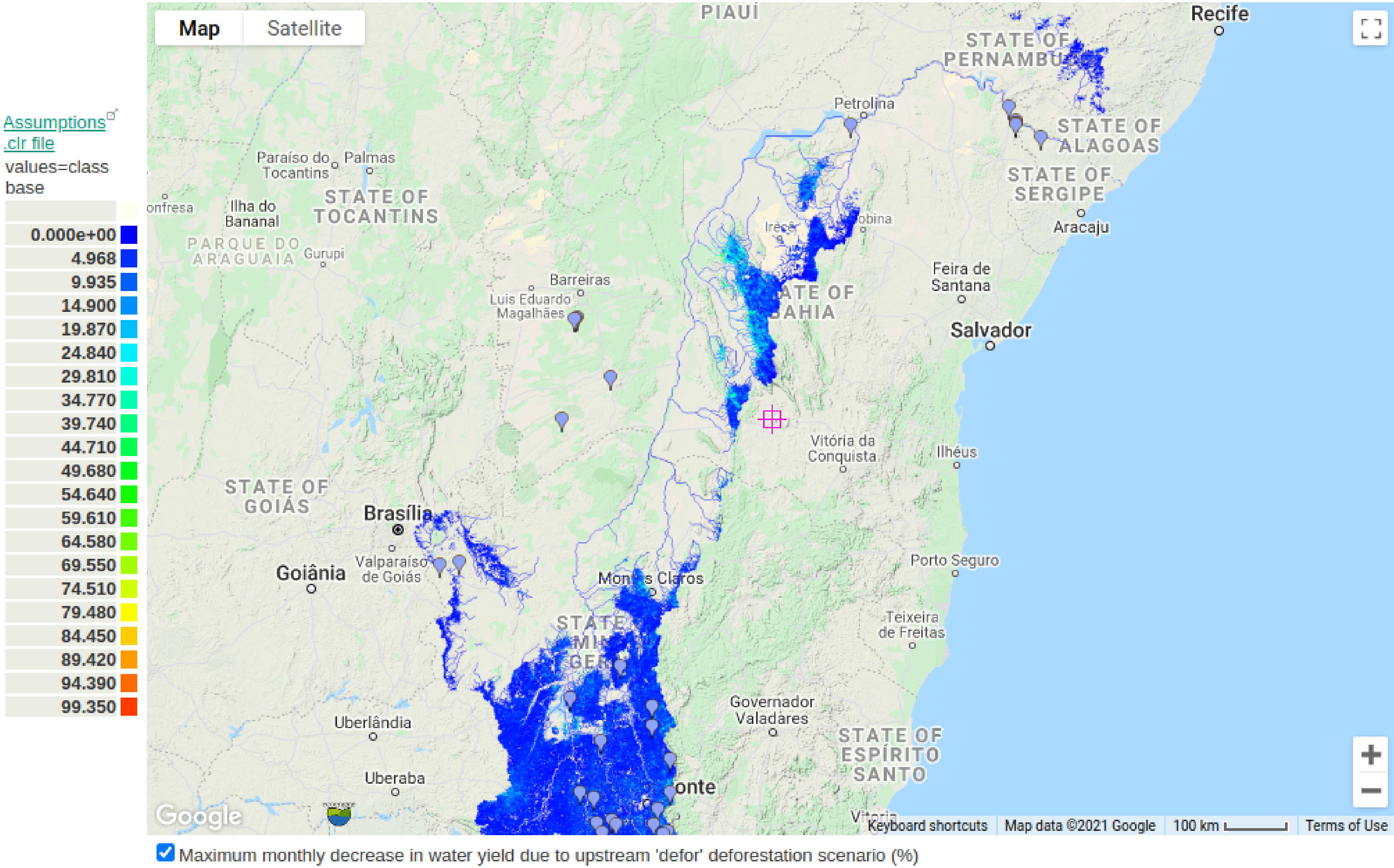


Hydrological influence of upstream 'defor' deforestation scenario (%)

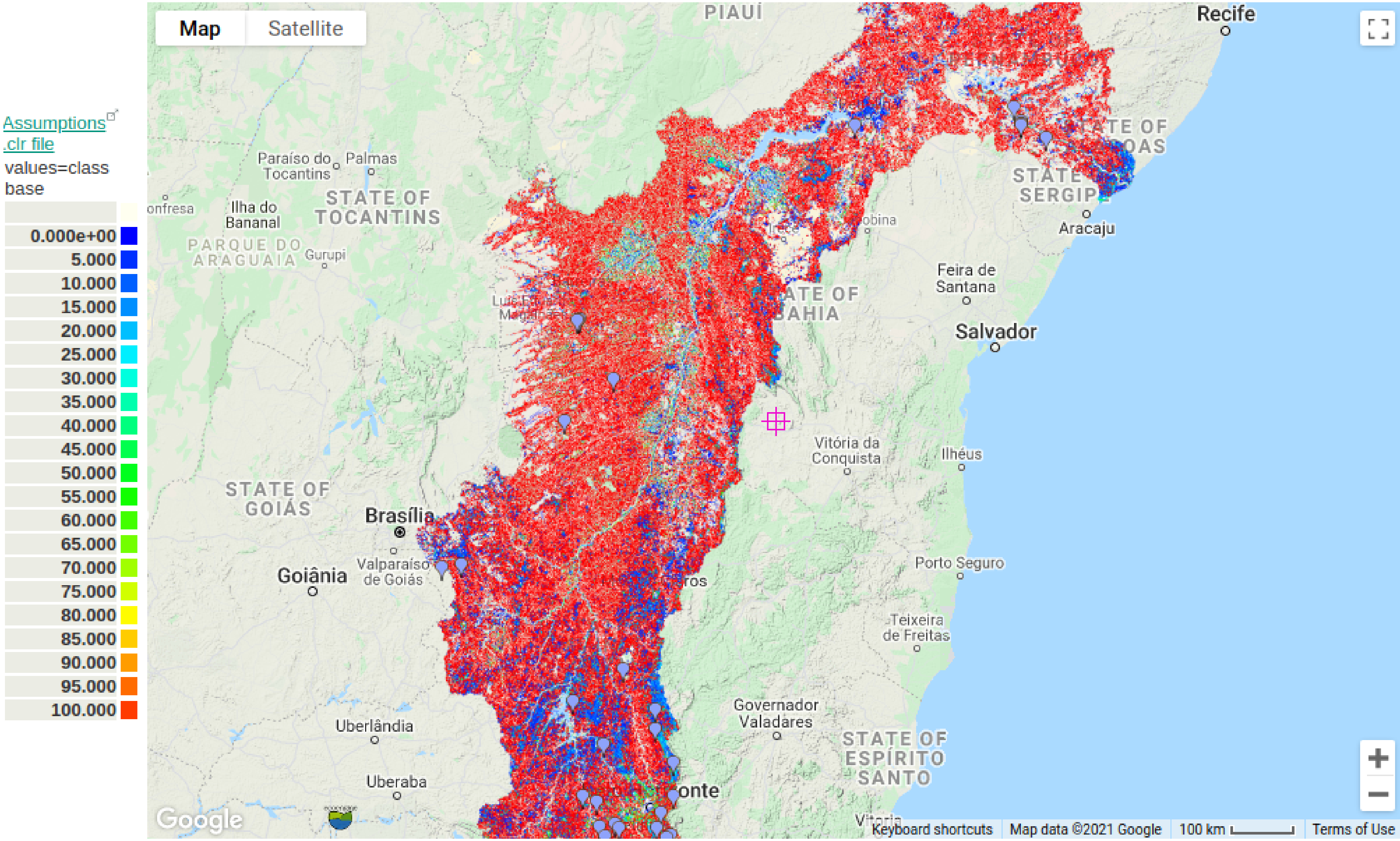
RI7 Decrease in water yield due to upstream 'defor' deforestation scenario (%) [there are no decreases, all increases]



RI8 Maximum monthly decrease in water yield due to upstream 'defor' deforestation scenario (%) [there are no decreases, all increases]

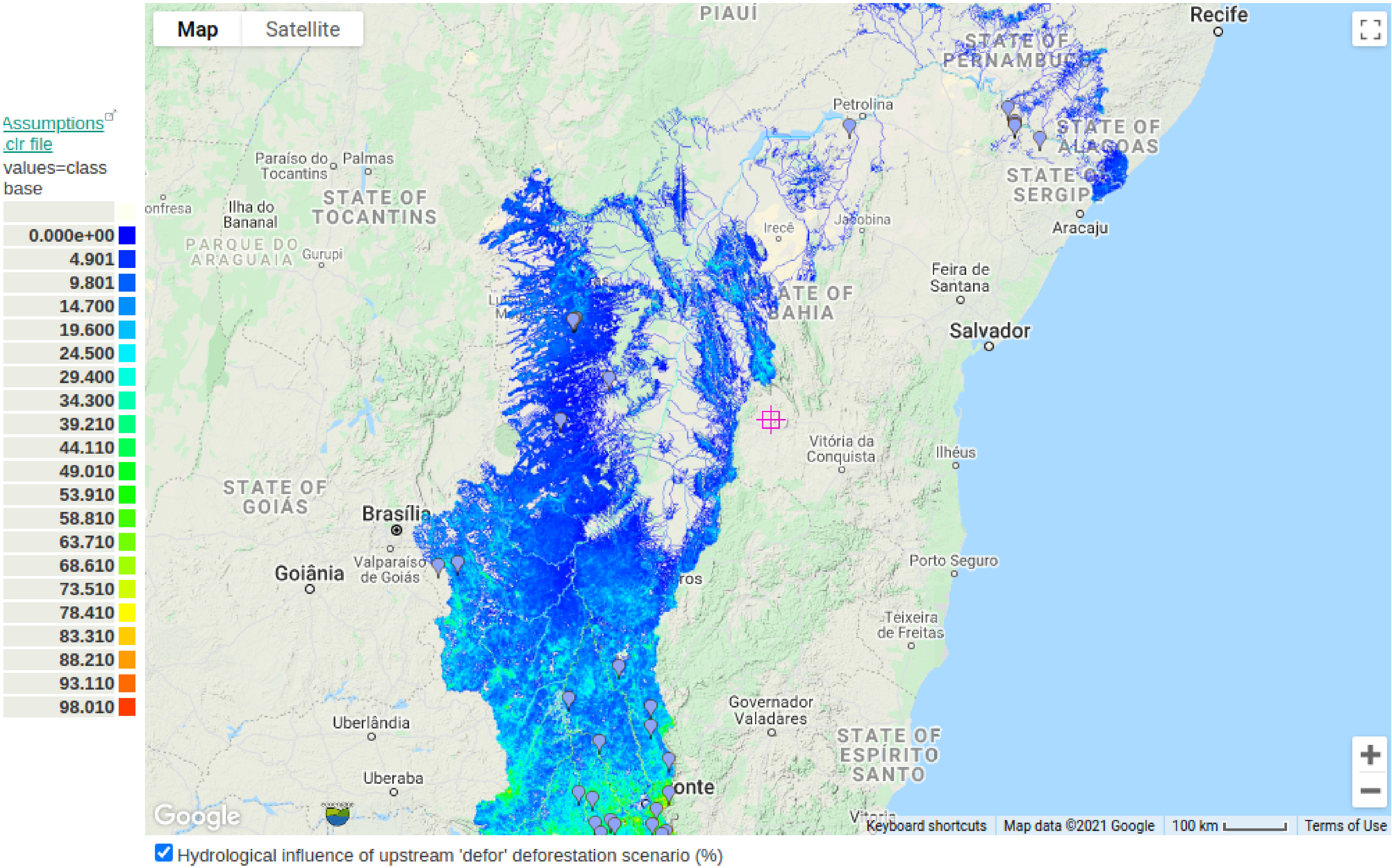


RI9 Increase in sediment transport due to upstream 'defor' deforestation scenario (%)



Increase in sediment transport due to upstream 'defor' deforestation scenario (%)

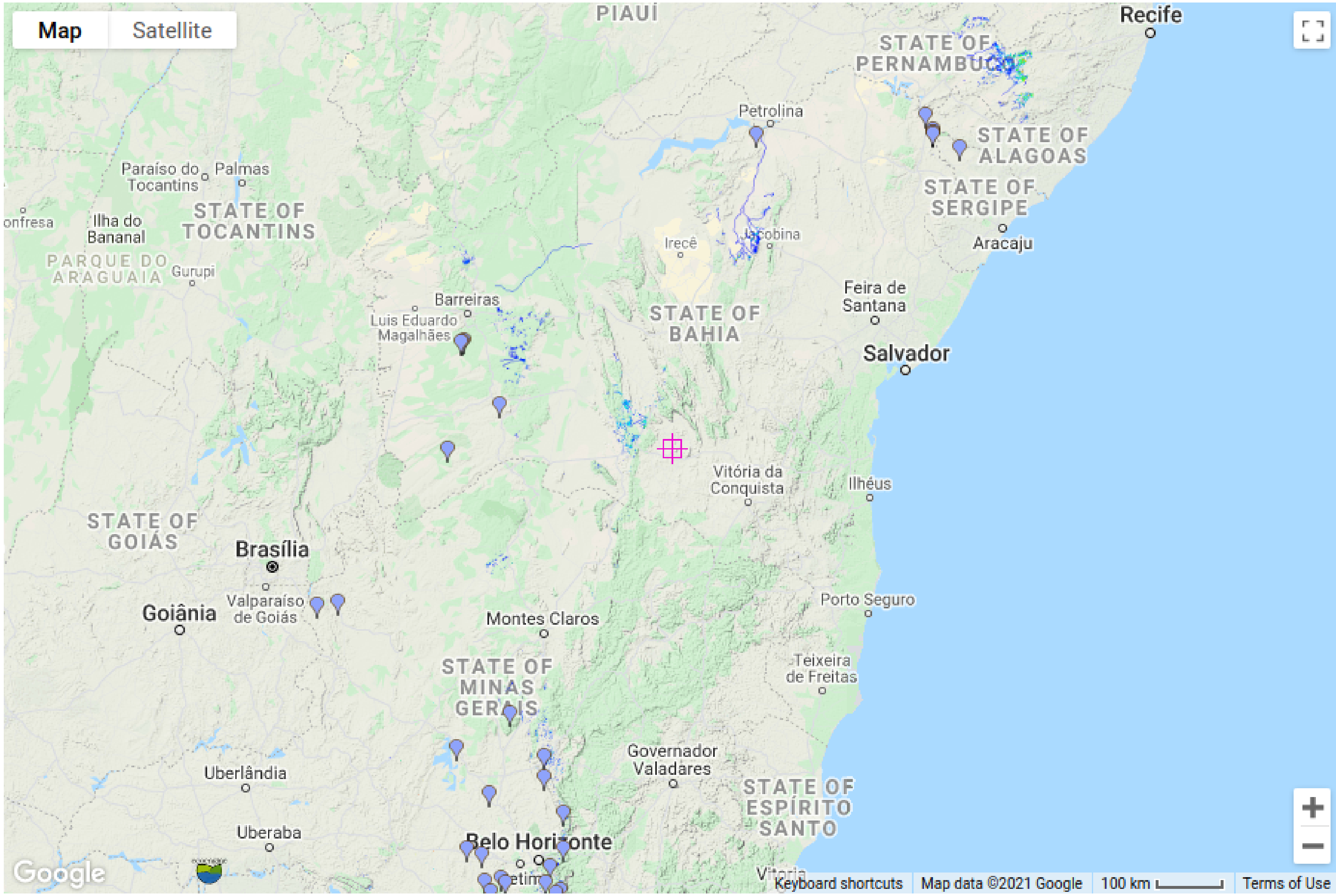
RE1 Hydrological influence of upstream 'refor' restoration scenario (% of inputs)



RE2 Increase in water yield due to upstream 'refor' restoration scenario (%)

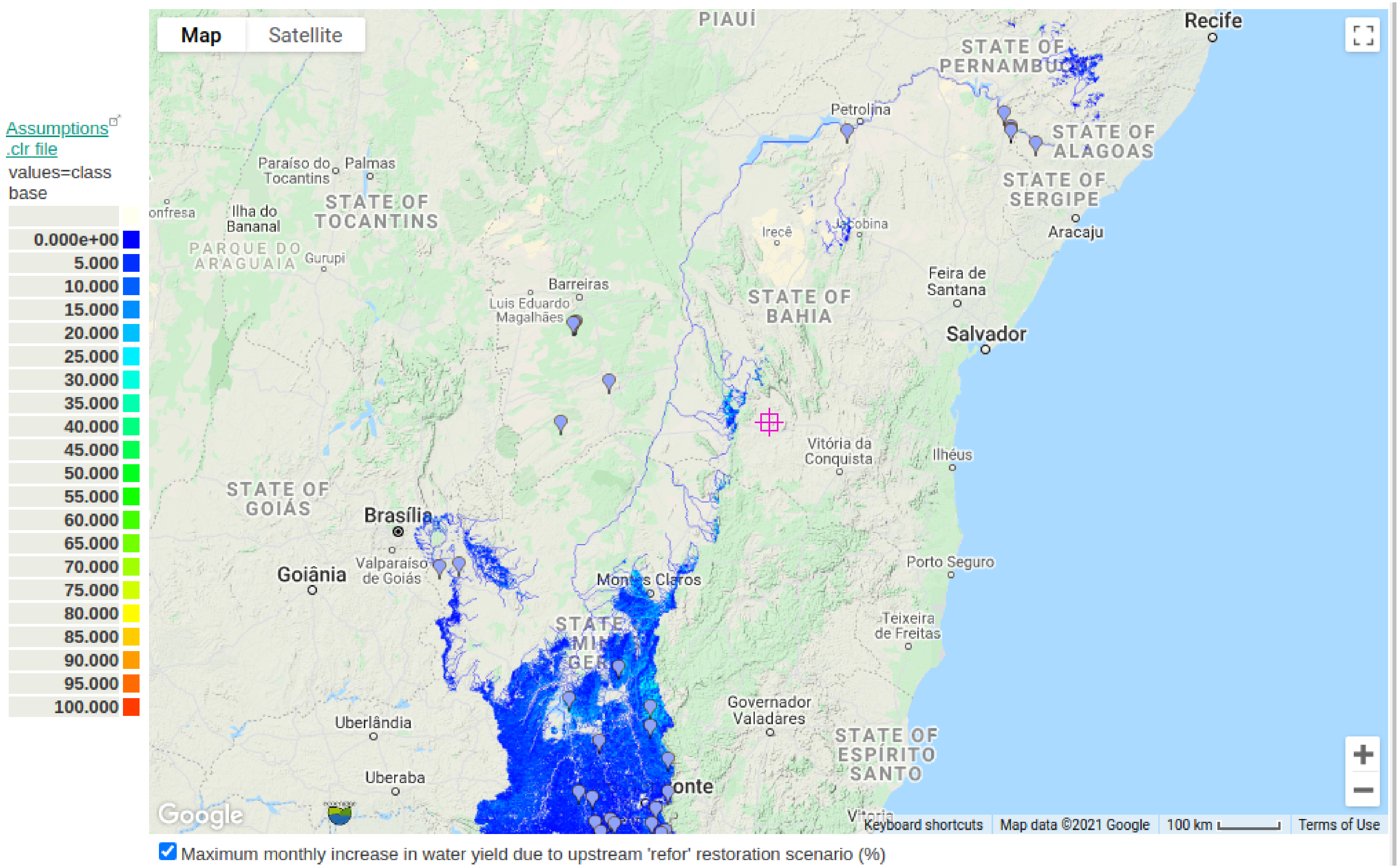
Assumptions
.clr file
values=class base

0.000e+00	
0.239	
0.479	
0.718	
0.957	
1.196	
1.436	
1.675	
1.914	
2.154	
2.393	
2.632	
2.872	
3.111	
3.350	
3.589	
3.829	
4.068	
4.307	
4.547	
4.786	

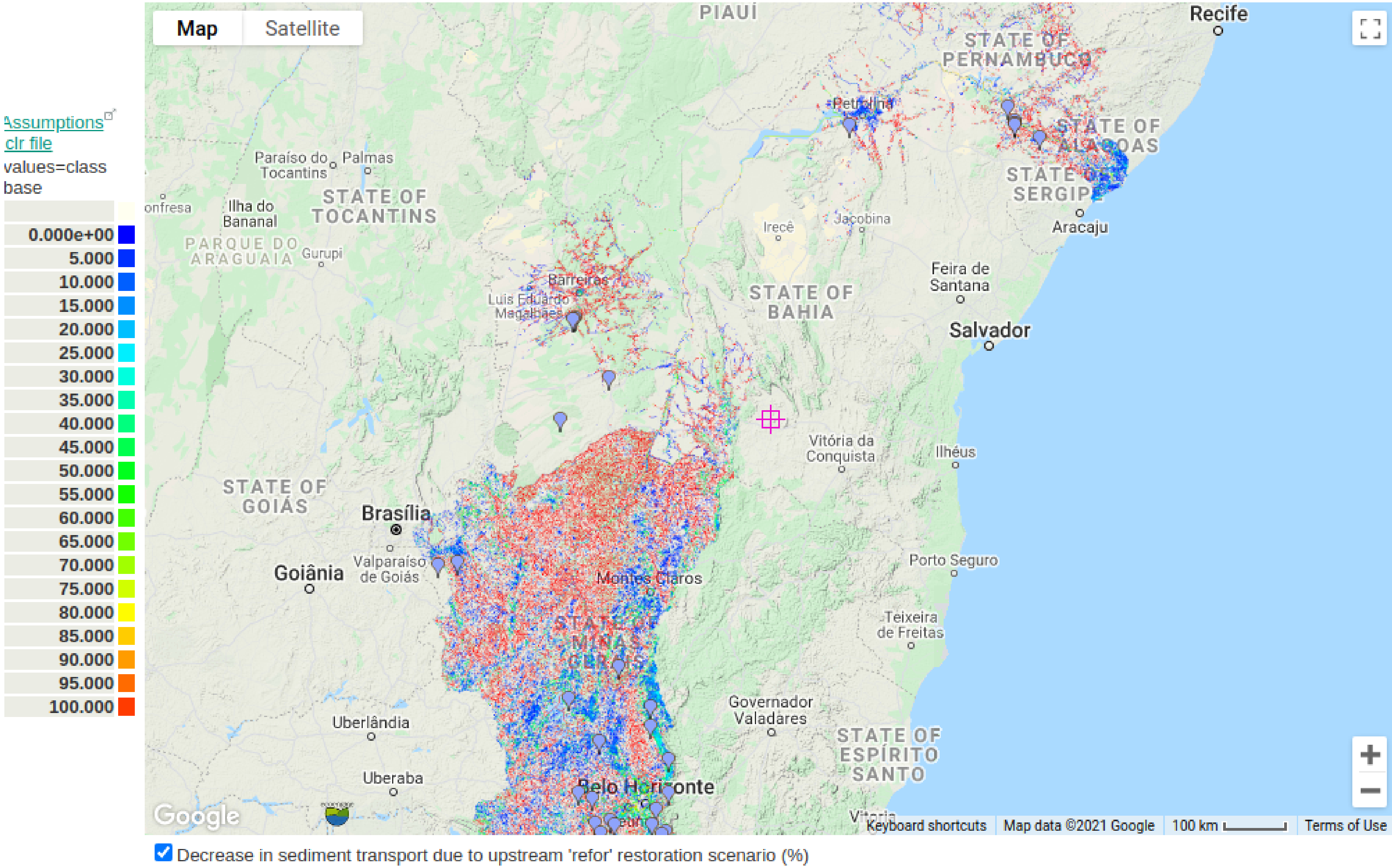


☑ Increase in water yield due to upstream 'refor' restoration scenario (%)

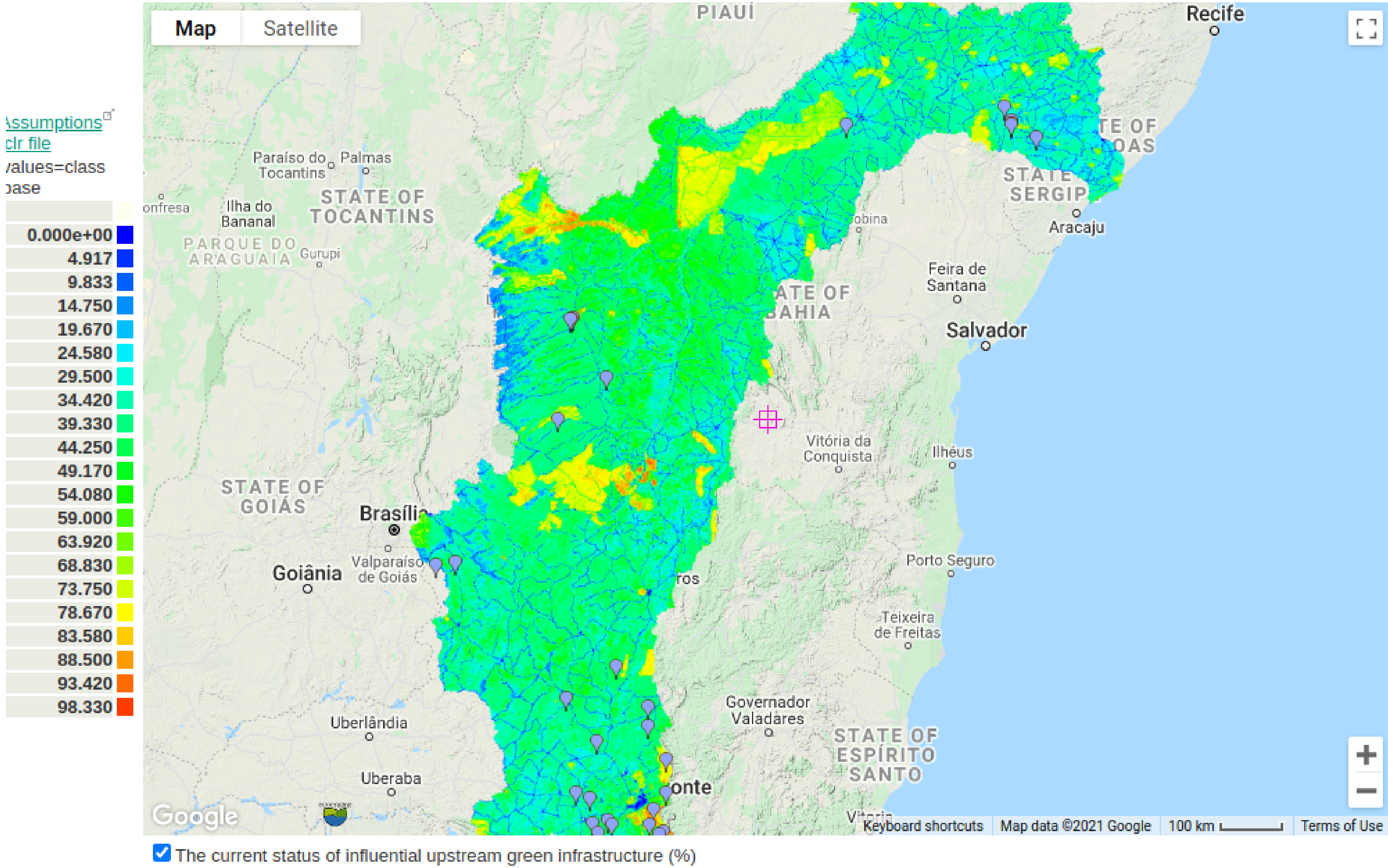
RE3 Maximum monthly increase in water yield due to upstream 'refor' restoration scenario (%)



RE4 Decrease in sediment transport due to upstream 'refor' restoration scenario (%)



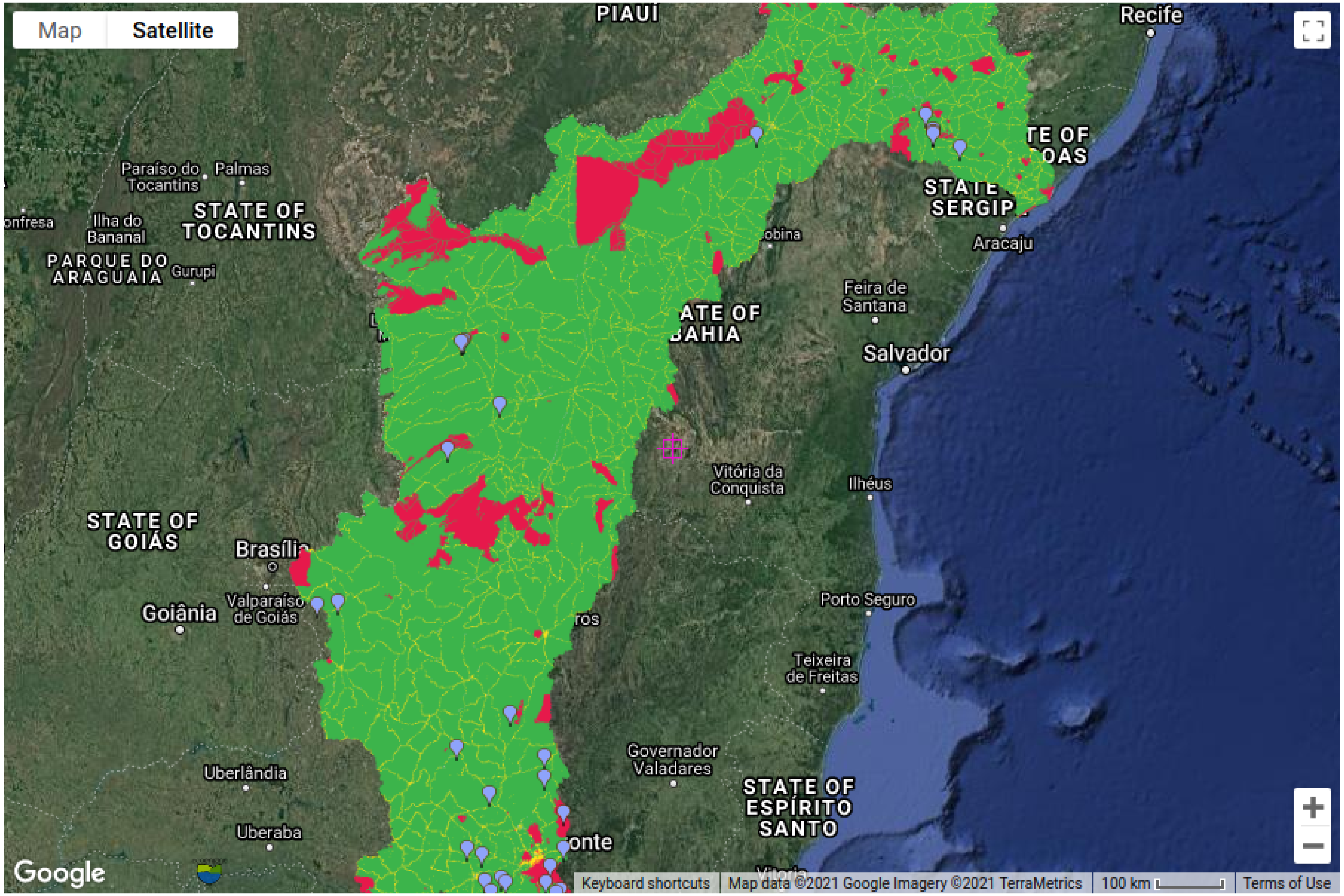
STFinal The current status of influential upstream green infrastructure



GreatestST The most influential upstream green infrastructure

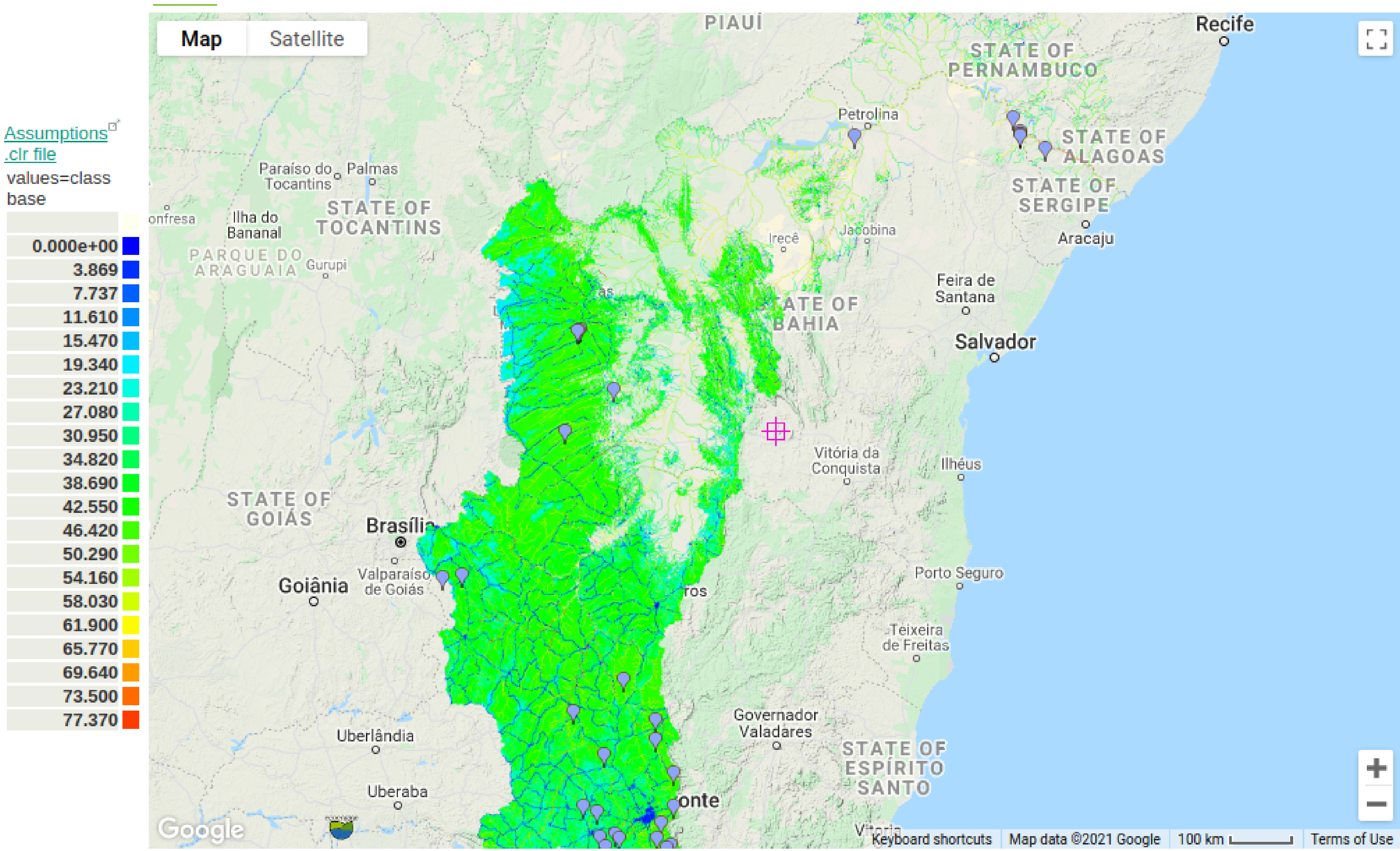
Assumptions
.clr file

	0	None
	1	Upstream protected area (%)
	2	Upstream semi-natural area (%)
	3	Upstream forest area (%)



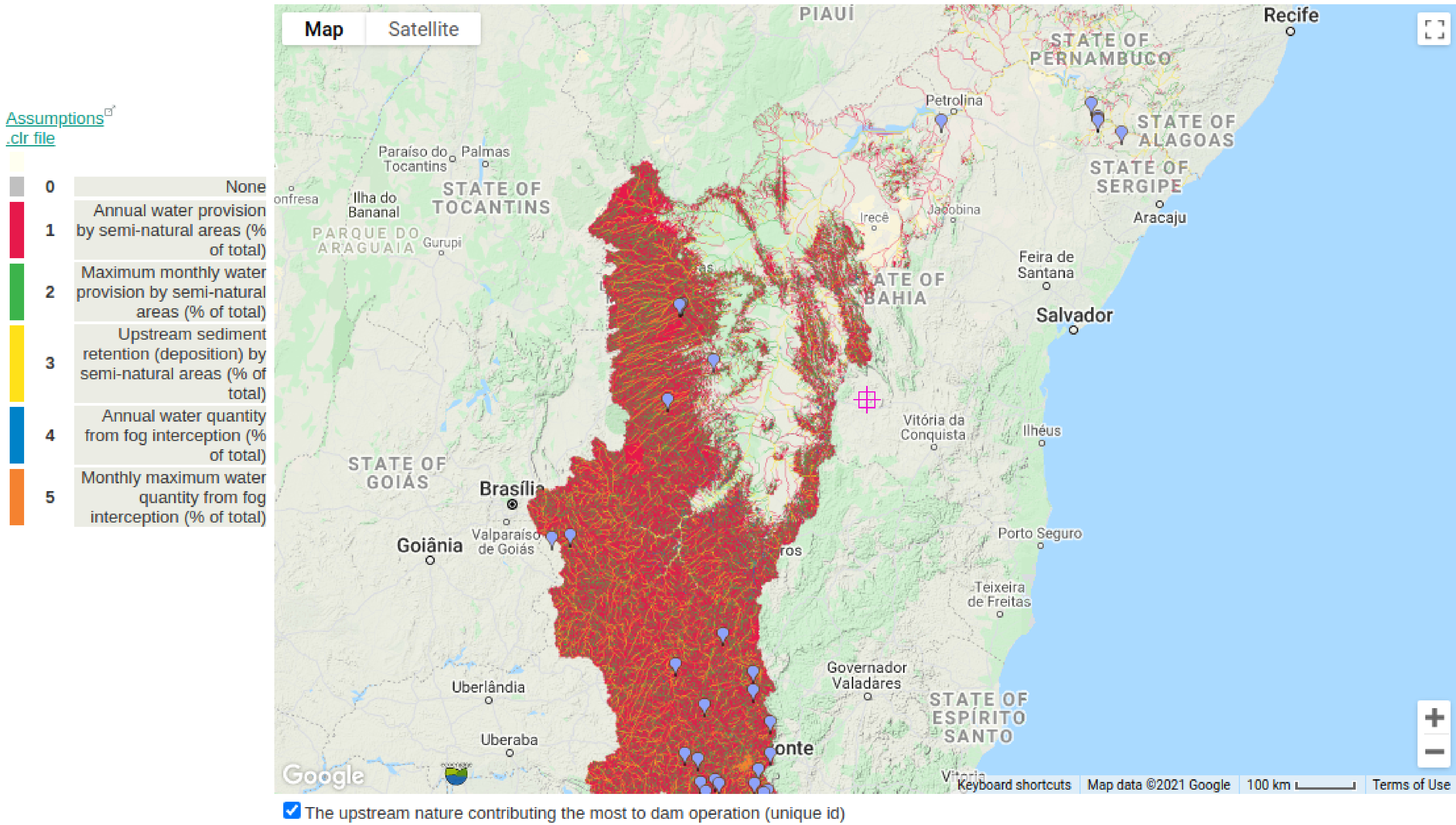
The most influential upstream green infrastructure (unique id)

COFinal The overall contribution of upstream nature to dam operation

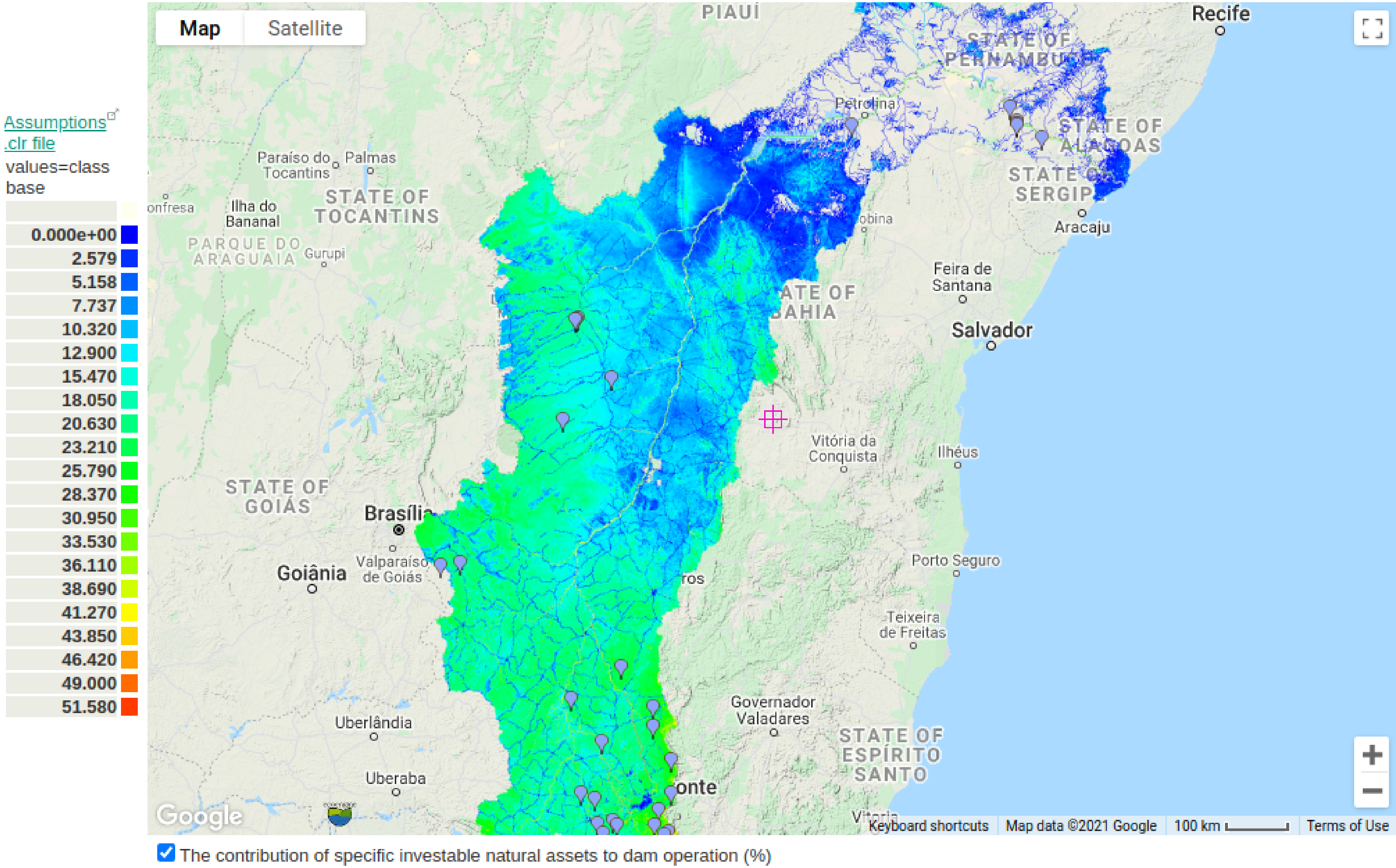


The overall contribution of upstream nature to dam operation (%)

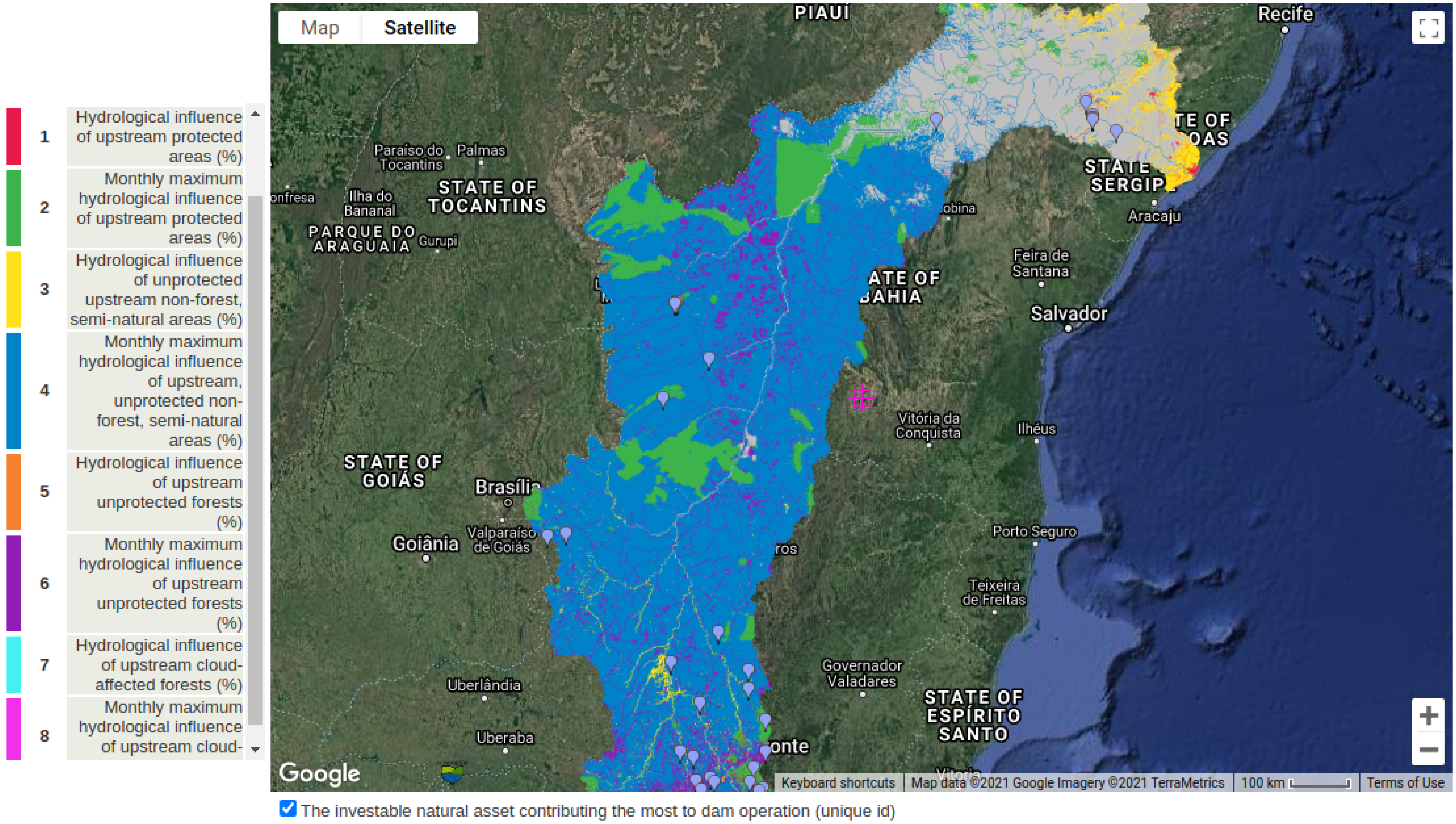
GreatestCO The upstream nature contributing the most to dam operation



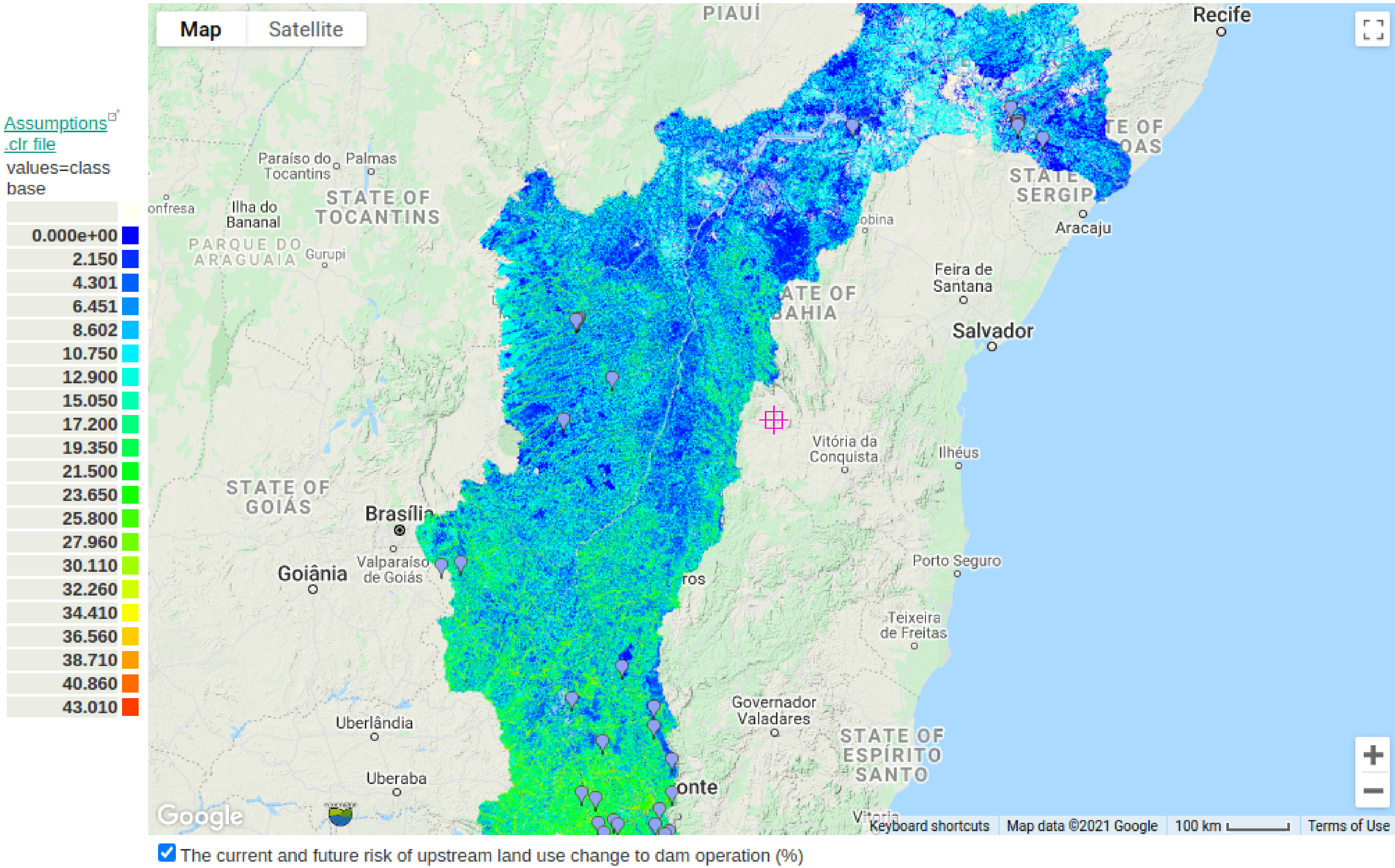
ASFinal The contribution of specific investable natural assets to dam operation



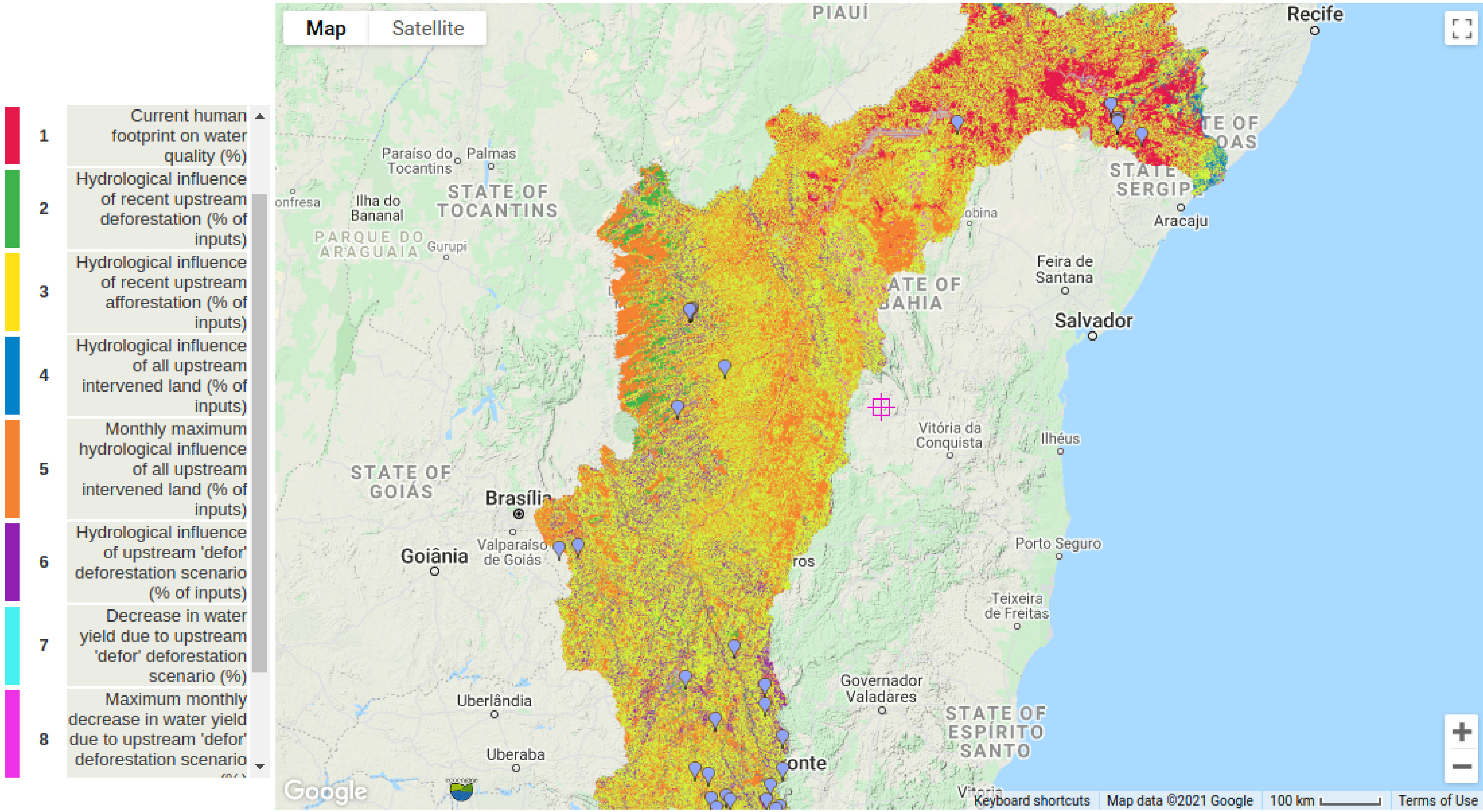
GreatestAS The investable natural asset contributing the most to dam operation



RIFinal The current and future risk of upstream land use change to dam operation

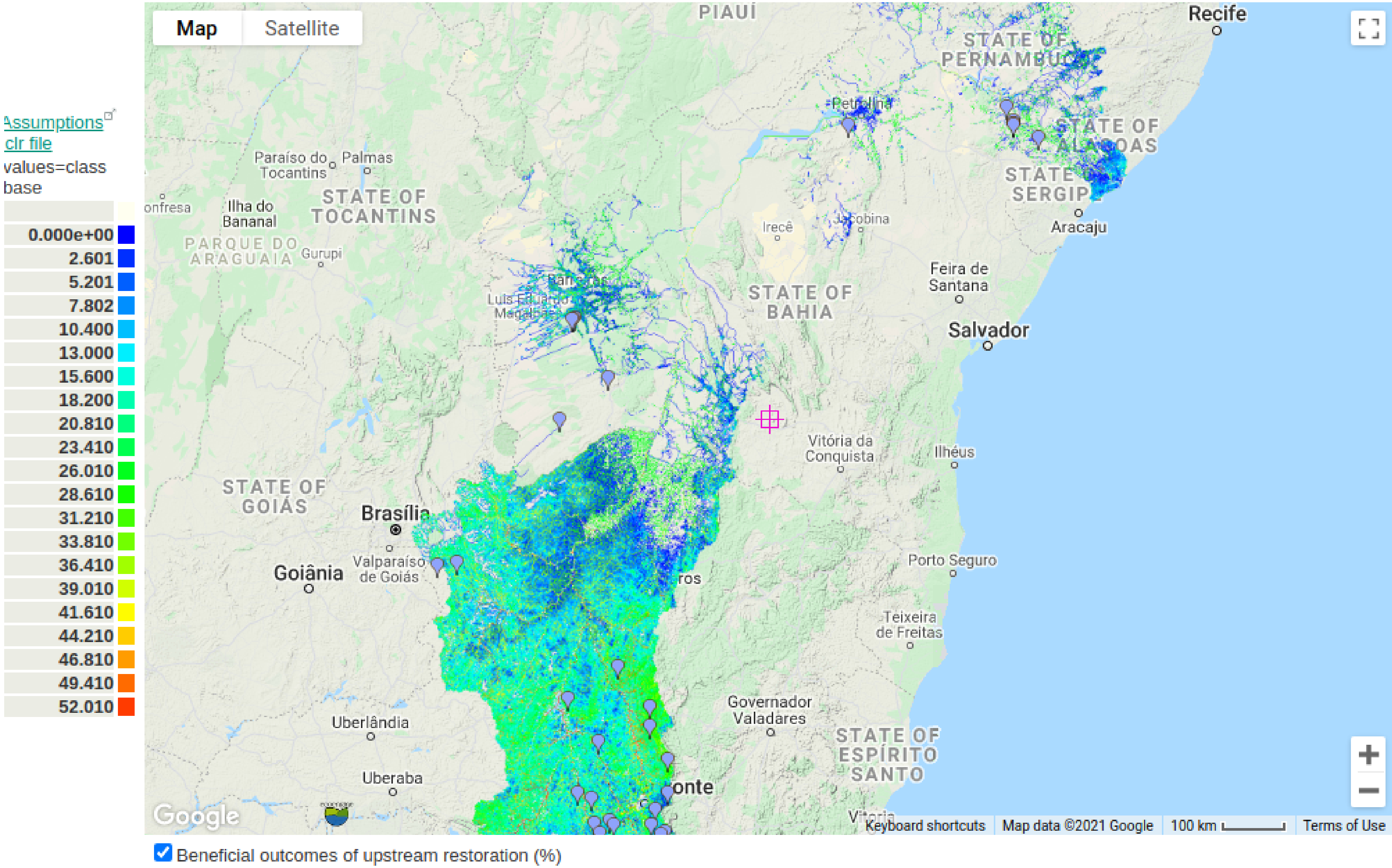


GreatestRI The greatest current and future risk to dam operation associated with upstream land use change



The greatest current and future risk to dam operation associated with upstream land use change (unique ids)

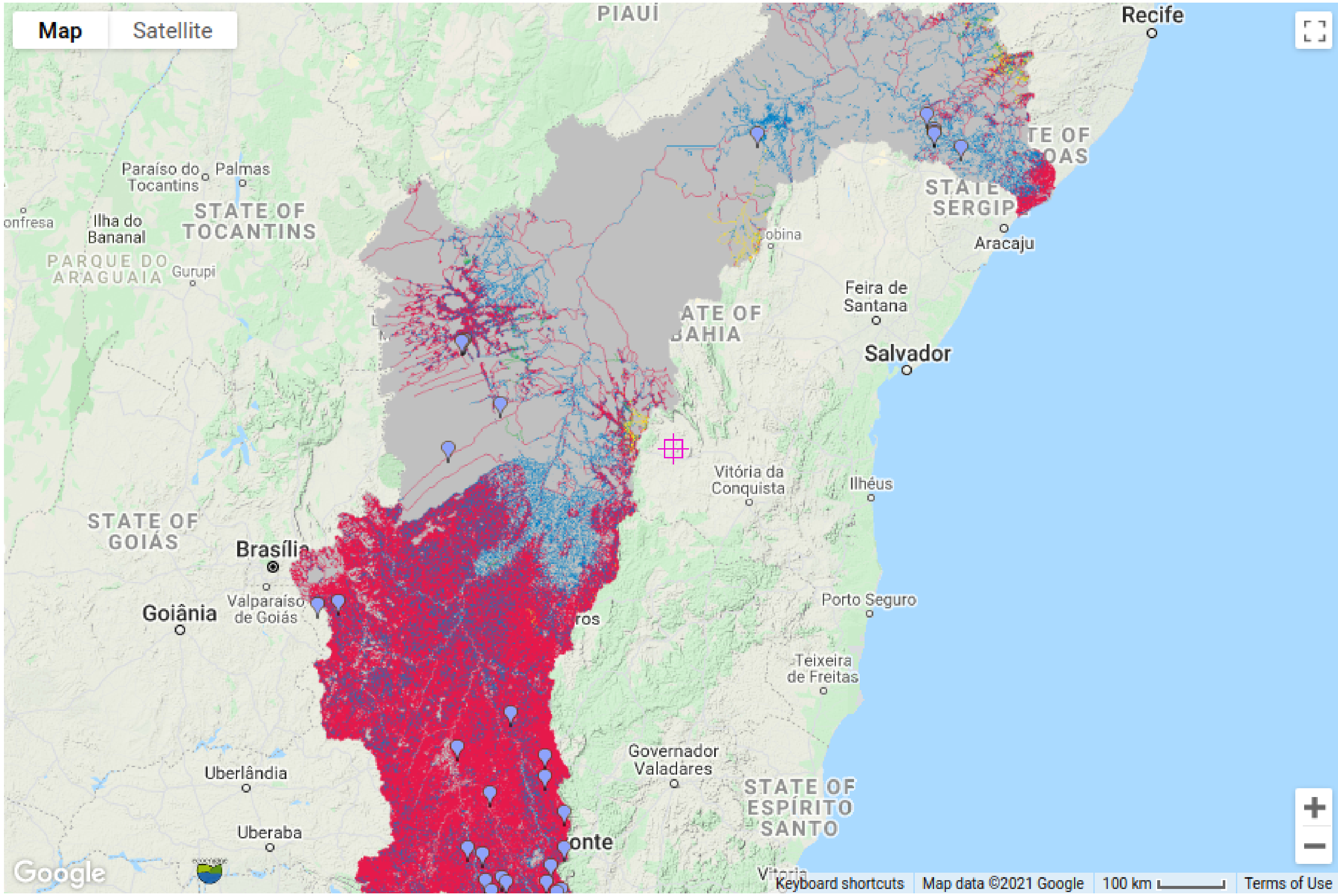
REFinal The magnitude of beneficial outcomes for the dam of restoration of upstream green infrastructure



GreatestRE The greatest beneficial outcome of restoration of upstream green infrastructure

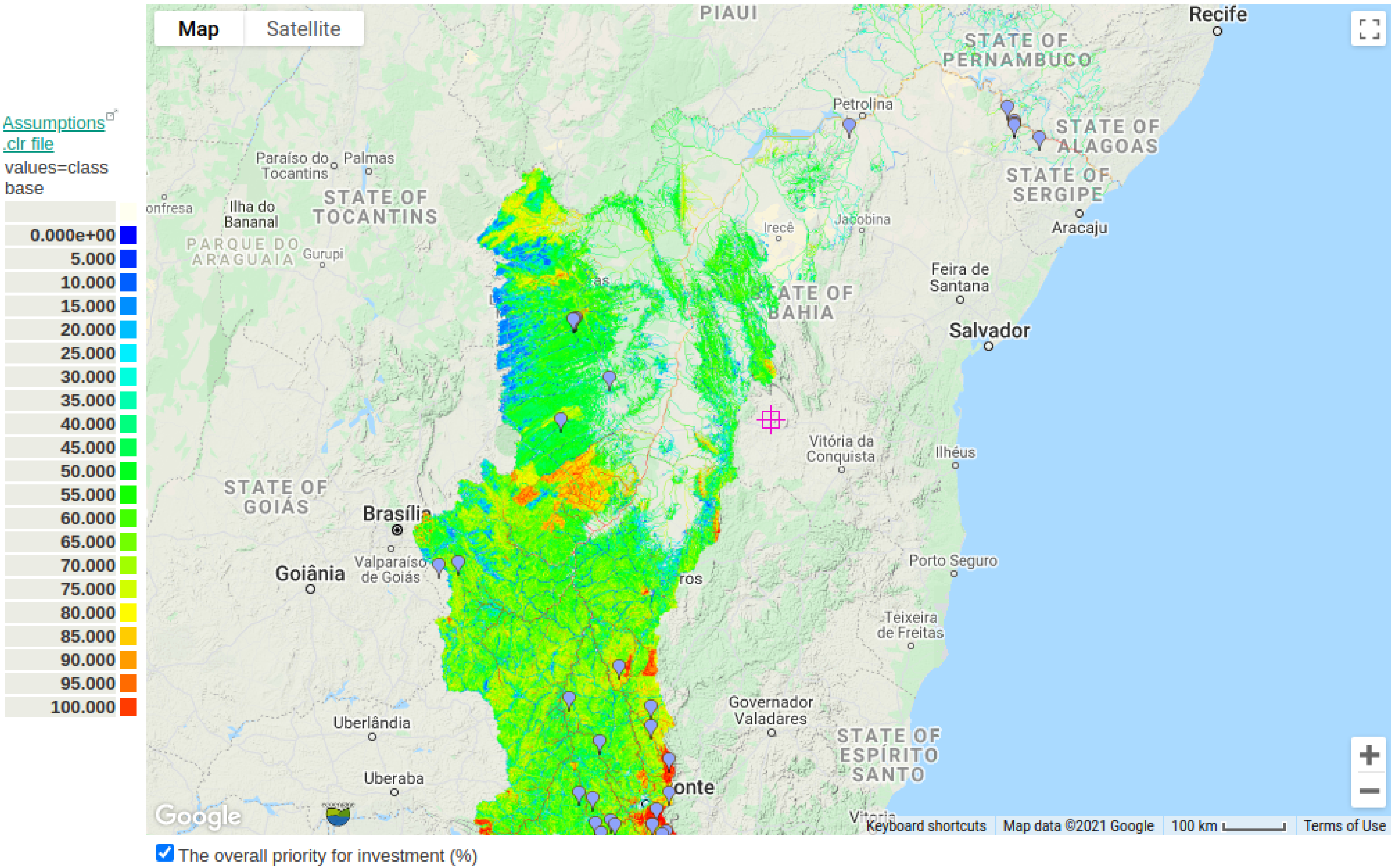
Assumptions
.clr file

0	None
1	Hydrological influence of upstream 'refor' restoration scenario (% of inputs)
2	Increase in water yield due to upstream 'refor' restoration scenario (%)
3	Maximum monthly increase in water yield due to upstream 'refor' restoration scenario (%)
4	Decrease in sediment transport due to upstream 'refor' restoration scenario (%)



The greatest beneficial outcome of restoration of upstream green infrastructure (unique id)

OverallPri The overall priority for investment



GreatestPri The greatest priority for investing

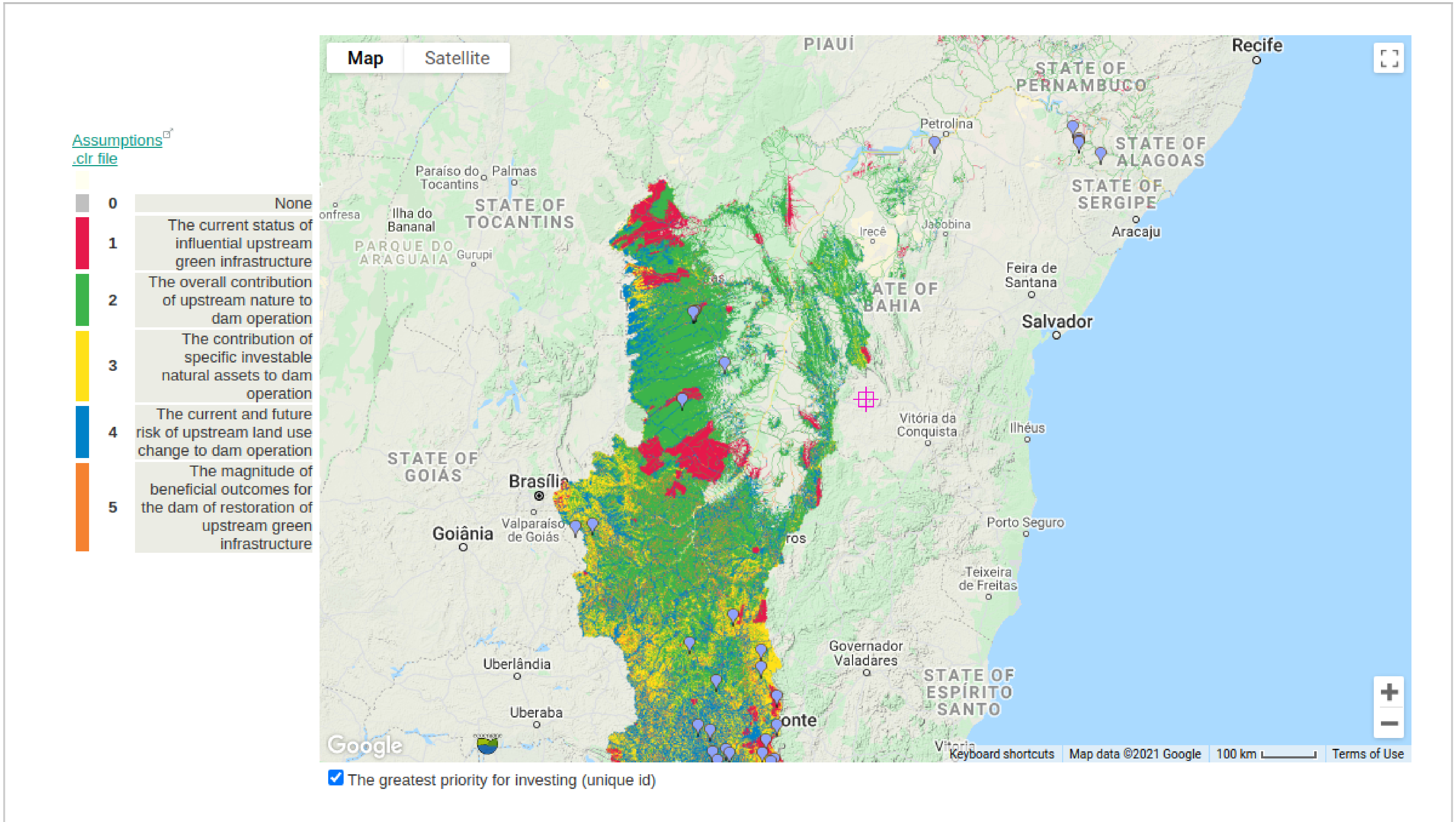


Table 4 Maps for the individual and combined metrics for the Sao Francisco basin