VOLUME IA

Hydrogeological Atlas of the Northern Regions of Ghana

Agence canadienne de développement international

Canadian International Development Agency

WRC Water Resources Commission

FINAL TECHNICAL REPORT

Hydrogeological Assessment Project of the Northern Regions of Ghana (HAP)

December 2011

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SNC·LAVALIN International

INRS Université d'avant-garde

Hydrogeological assessment project of the northern regions of Ghana

Hydrogeological Atlas

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[5] Geological Survey of Canada, Quebec, Canada

December 2011

Introduction

This hydrogeological atlas was prepared under the Hydrogeological assessment project (HAP) of the northern regions of Ghana as a complement for the final technical report. The purpose of the atlas is to provide a graphical overview of the regional hydrogeological context of northern Ghana. Maps and thematic plates present data compiled and interpreted during the implementation of the HAP. Maps presented in this atlas only provide regional data trends and may thus not be accurate locally. For specific information pertaining to each map/plate, the reader should consult the final technical report.

Project summary and objectives

The HAP was designed to contribute to the collection and analysis of scientific data on groundwater with the long term objective of improving groundwater resource management and development in the three northern regions of Ghana. As such, the HAP would contribute towards achieving the WATSAN targets set within the Ghana Poverty Reduction Strategy through an enhanced knowledge base and understanding of the hydrogeological conditions in the north of Ghana. The HAP was implemented between February 2006 and December 2011. The SNC-Lavalin Inc. and Institute National de la Recherche Scientifique (INRS) Joint Venture was selected by the Canadian International Development Agency (CIDA) as the Canadian Executing Agency (CEA) for the HAP. The project was implemented in conjunction with the Water Resource Commission (WRC) of Ghana, the key project stakeholder.

The project goal was to improve groundwater resource management and development in the north of Ghana. The project purpose was to improve the knowledge base and understanding of the hydrogeological setting in the north of Ghana, and to contribute to the capacity development primarily of the personnel of the Water Resource Commission (WRC) and its partner institutions in technical and institutional aspects of groundwater planning and development. As such, targeted project outcomes were:

- Increased access, by Ghanaian water resources institutions and other relevant agencies, to accurate groundwater resource information for the north of Ghana;
- Enhanced technical and institutional capacity of Ghanaian water resource institutions in the collaborative management of groundwater resources.

The approach of the project was to achieve the expected results through two main thrusts:

- A hydrogeological assessment consisting of synthesis of existing data and contribution to the collection and analysis of additional data through dedicated, consensus-driven pilot projects such as:
  - Data collection
  - Borehole test drilling
  - Aquifer parameter testing
  - Groundwater sampling and analyses
  - Thematic Mapping
  - Workshops and trainings
- Capacity Building comprising technical capacity building focusing primarily on database management and resource development, but also including non-technical capacity building focusing primarily on enhancing the capacities of WRC in networking and in communicating.

Acknowlegements

The preparation of this atlas, which was done by the SNC/INRS Joint Venture and supported by the Canadian International Development Agency (CIDA) and the Government of Ghana, was made possible by the collaboration of many organizations and institutions. The following organizations notably provided support either through supply of information or review of HAP products:

- Ghana Water Research Institute
- Community Water and Sanitation Agency
- Ghana Geological Survey Department
- Ghana Meteorological Services Department
- Ghana Soil Research Institute
- Northern Region Water & Sanitation Project (NORWASP)
- Globalen Wasserkreislauf (GLOWA-Volta Project)
- Solar & Wind Energy Resource Assessment
- Geological Survey of Denmark & Greenland
- British Geological Survey laboratory
- European Union
- Agence Française de Développement
- World Vision International
- Unihydro Ltd

For bibliographic and reference purposes, this atlas should be cited as:

> Carrier, M.-A., Aubut, R., Lefebvre, R., Racicot, J., Asare, E.B., Gravel, E., Rivera, A. (2011) Hydrogeological atlas - Hydrogeological assessment project of the northern regions of Ghana. Document submitted to the Canadian International Development Agency (CIDA) by SNC-Lavalin/INRS joint venture, December 2011, 58 p.

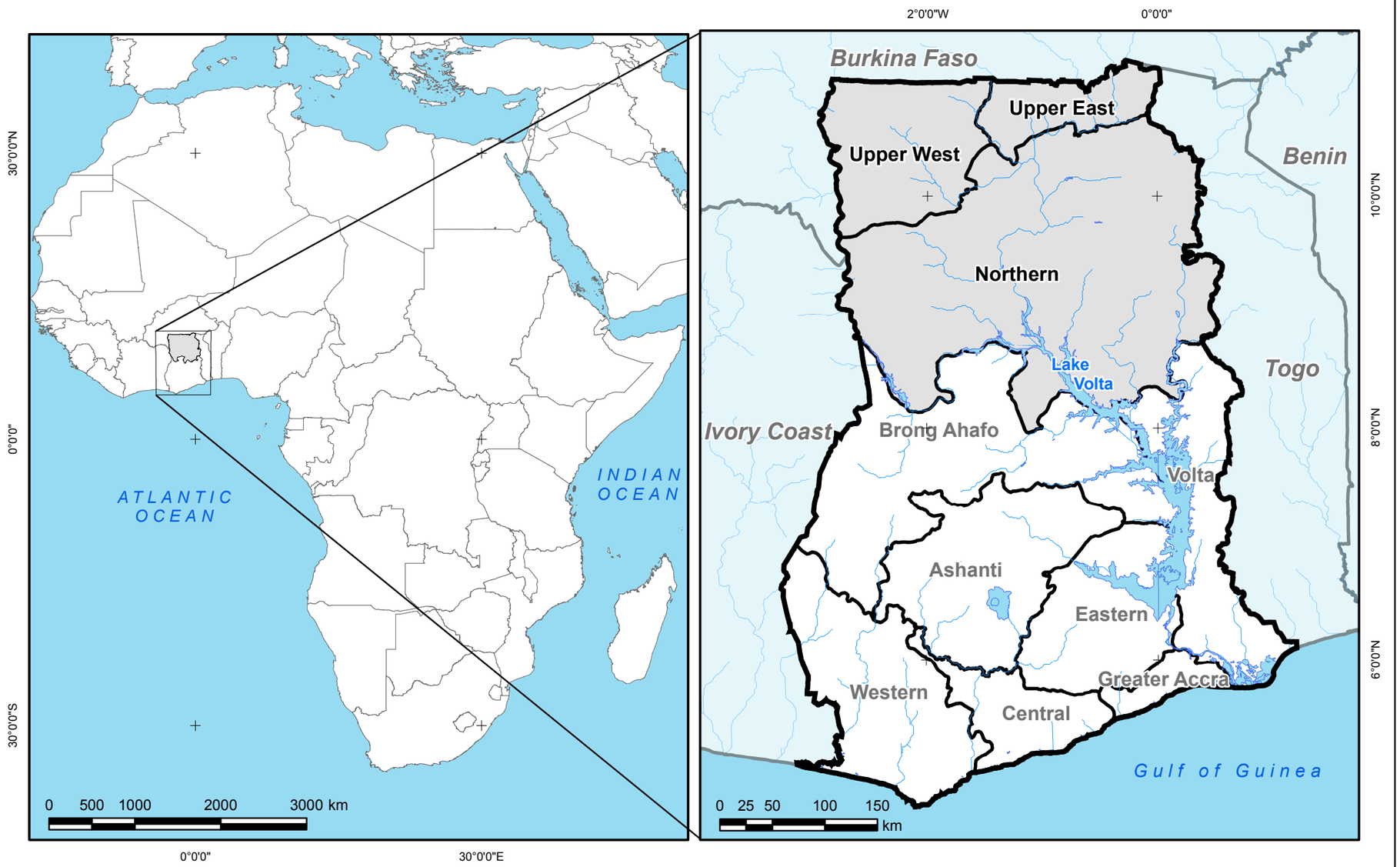
Map format

All maps are presented in A3 format with a scale of 1 : 1750000 unless otherwise specified. The following coordinate projection is used for all maps:

Name: Ghana Metre Grid	Latitude of origin: 4.67
Projection: Transverse Mercator	Longitude of origin: -1.00
Datum: D_Leigon (1978)	Scale factor: 0.999750
Units: Metre	False Easting: 274319.51

Table of content

Location and administrative limits



Limits

- Country
- Regions

Hydrography

- Lakes and oceans
- Rivers

Data source: All base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Location of study area

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 25 50 100 150 km

SLI 604138

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01	August 2011	Preliminary	M.-A. Carrier	-

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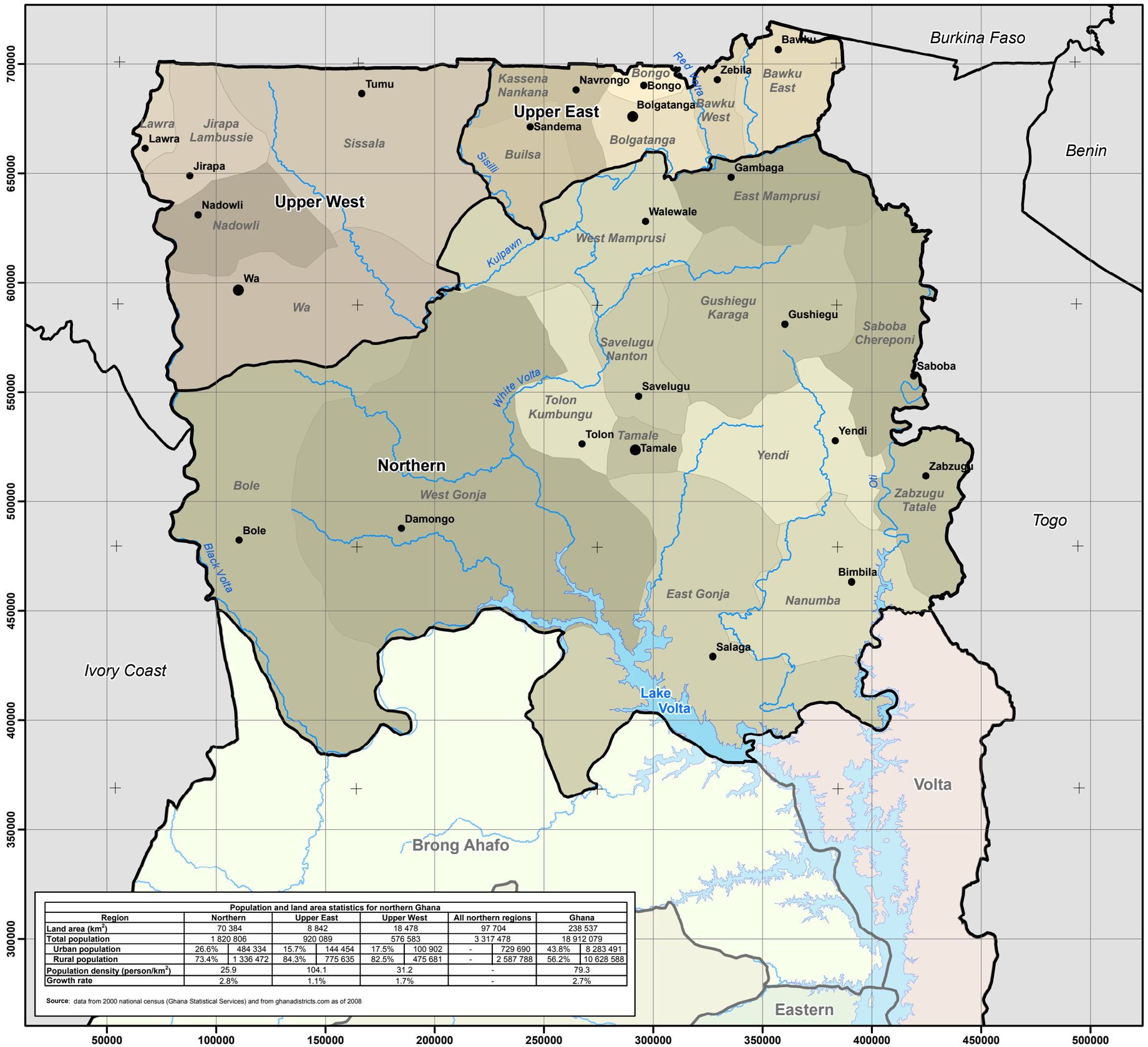

Population and land area statistics for northern Ghana

Region	Northern		Upper East		Upper West		All northern regions		Ghana	
Land area (km^2)	70 384		8 842		18 478		97 704		238 537	
Total population	1 820 806		920 089		576 583		3 317 478		18 912 079	
Urban population	26.6%	484 334	15.7%	144 454	17.5%	100 902	-	729 690	43.8%	8 283 491
Rural population	73.4%	1 336 472	84.3%	775 635	82.5%	475 681	-	2 587 788	56.2%	10 628 588
Population density (person/km^2)	25.9		104.1		31.2		-		79.3	
Growth rate	2.8%		1.1%		1.7%		-		2.7%	

Source: data from 2000 national census (Ghana Statistical Services) and from ghanadistricts.com as of 2008

Limits

- Country
- Regions
- Districts

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Data source: All base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Administrative limits

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

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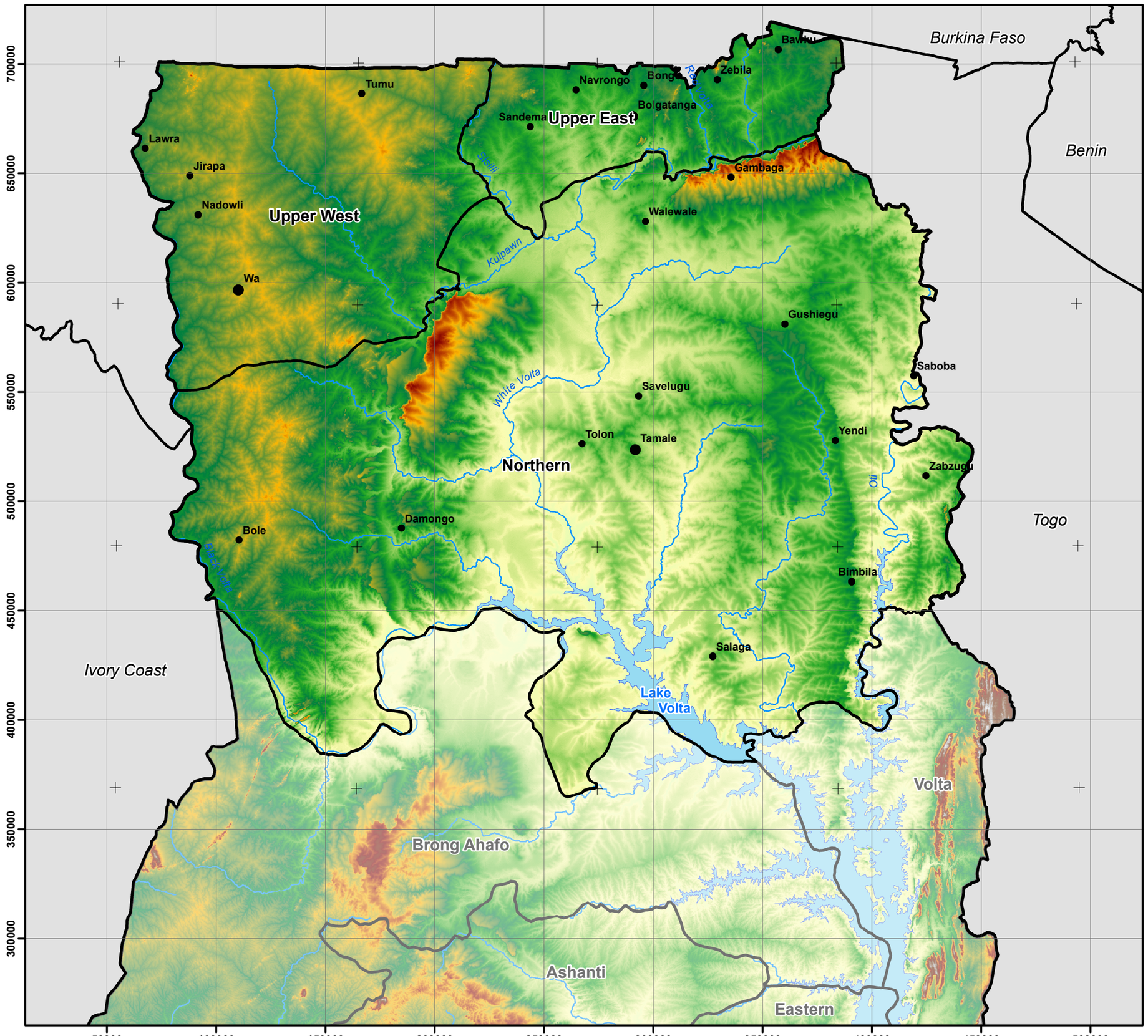
Physiography, land use and vegetation



Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Elevation (meters above sealevel)

High: 874

Low: 15

Data source: Elevation from CGIAR-CSI (SRTM data - version 4) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Topography

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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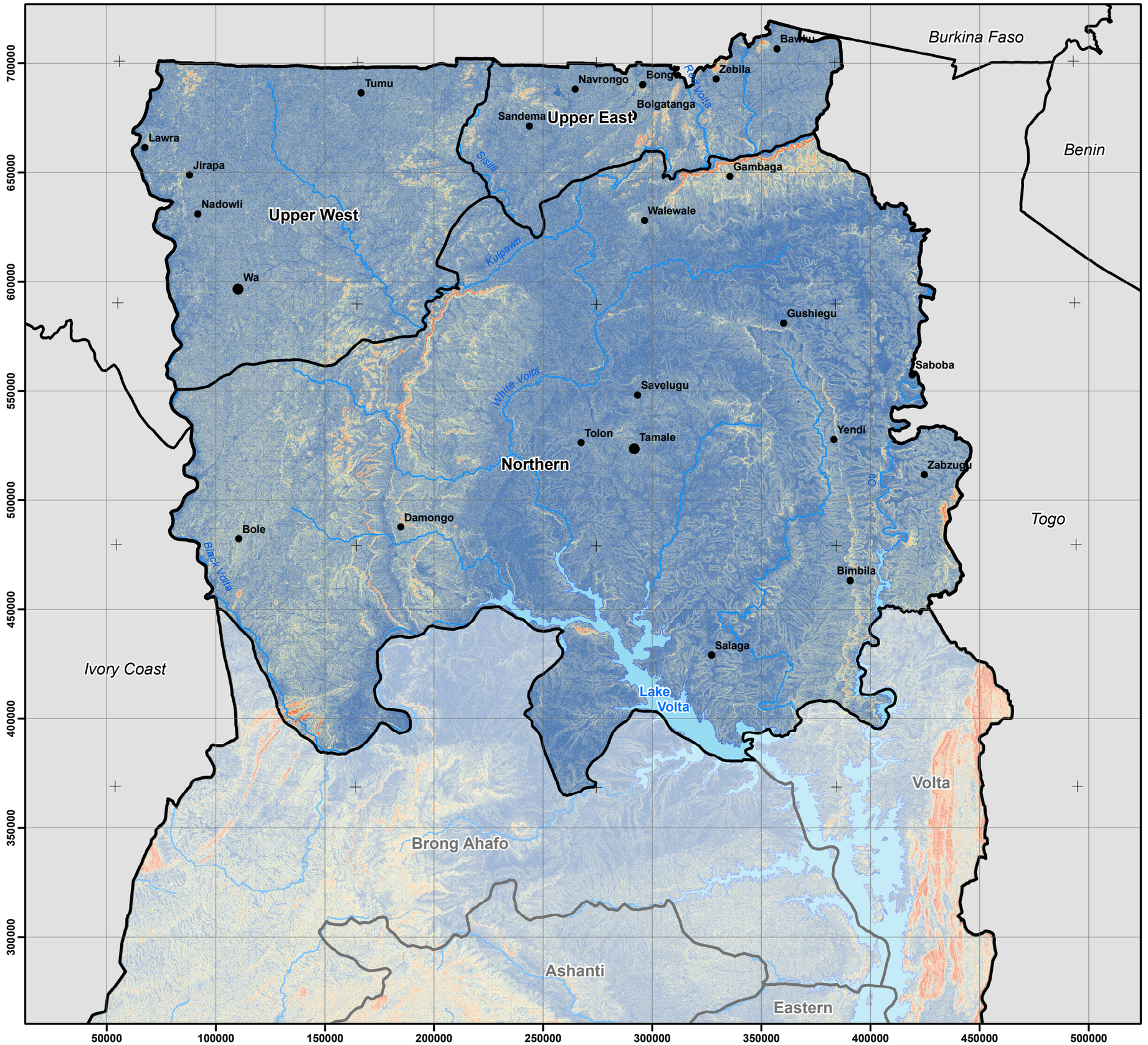

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Slope (degrees)

- 0 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 4
- 4 - 5
- 5 - 10
- 10 - 20
- 20 - 30
- > 30

Data source: Slope derived from elevation data using ArcGIS surface tools and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Slope

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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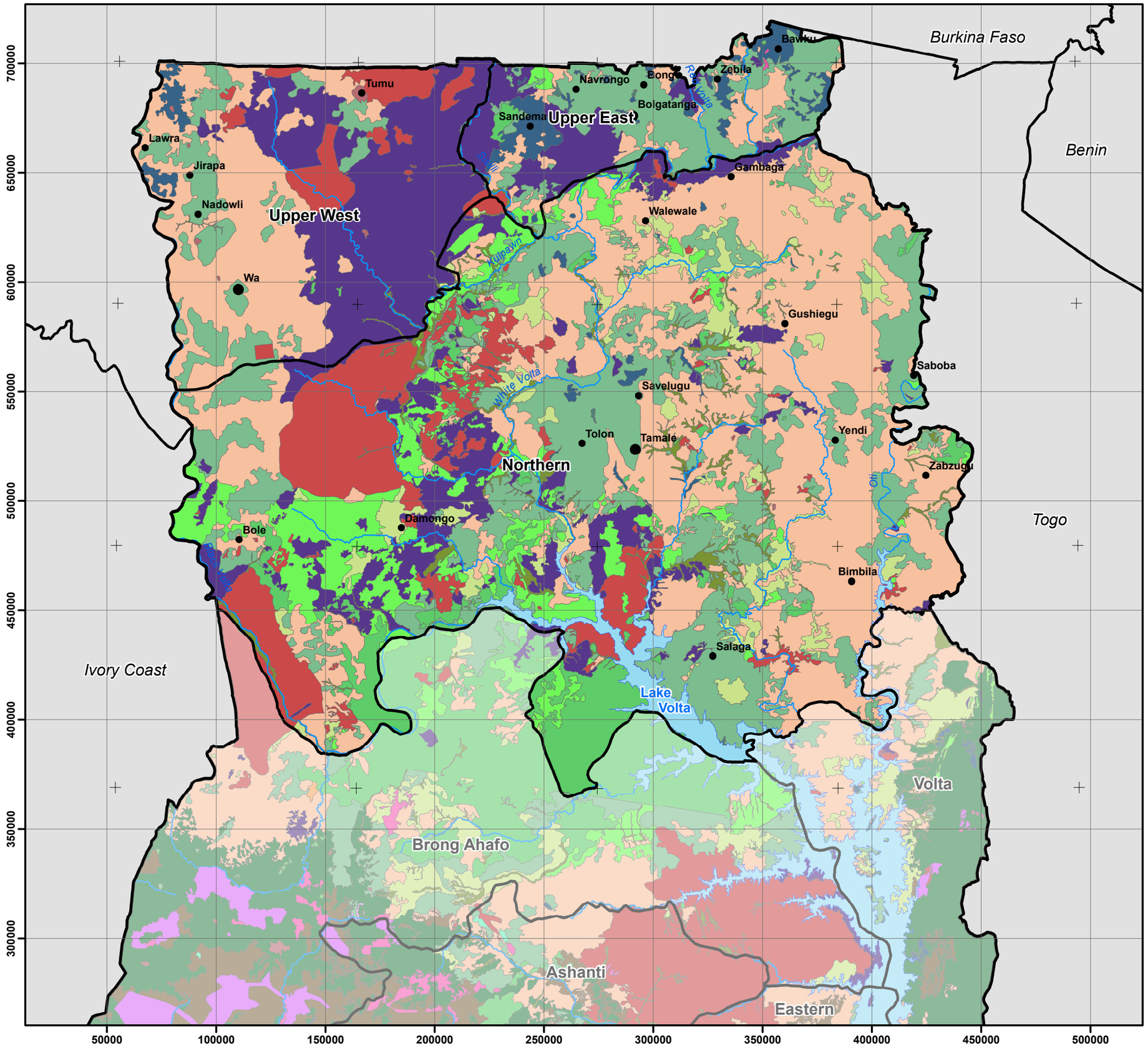

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Land use

- Closed cultivated savanna woodland
- Closed savanna woodland
- Grass and herb with or without scattered trees
- Grassland with or without scattered trees and shrubs
- Moderately closed tree canopy with herb and bush
- Moderately dense herb and bush with scattered trees
- Open cultivated savanna woodland
- Open forest
- Open savanna woodland
- Reservoir
- Riverine savanna vegetation
- Rock outcrop
- Shrub thicket with or without trees
- Unclassified (bushfire or cloud)
- Widely open cultivated savanna woodland

Data source: Land use and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Land use

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

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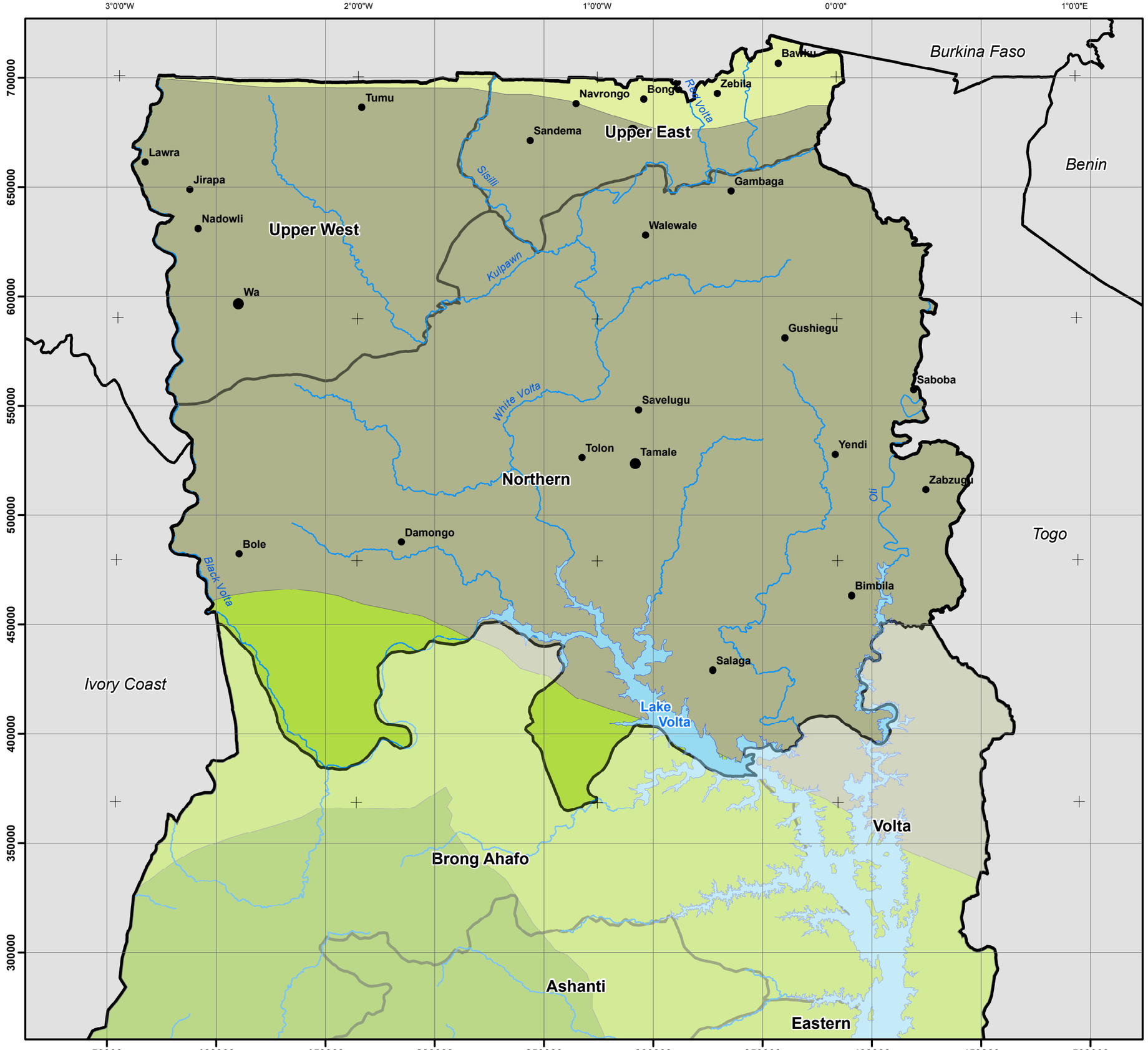

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Vegetation

- Coastal Savannah
- Guinea Savannah
- Moist Semi-Deciduous Tropical Forest
- Sudan Savannah
- Transitional Zone
- Tropical Rain forest

Data source: Vegetation zones from IWMI-GLOWA and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Vegetation

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

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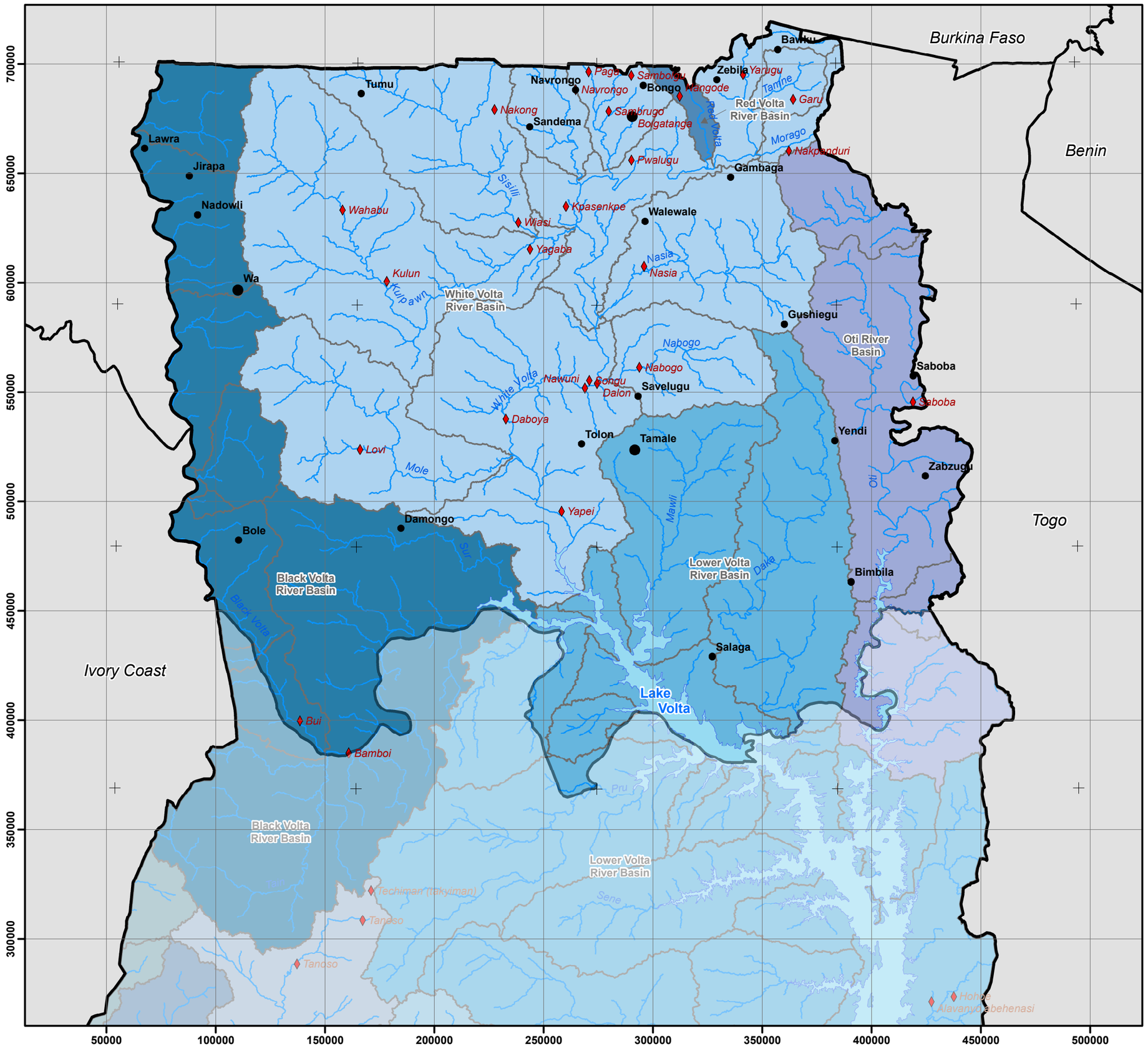
Hydrography and climate



Limits

Country

Settlements

Region capitals

District capitals

Hydrography

Lakes

Rivers

Basin

Black Volta River Basin

Red Volta River Basin

Lower Volta River Basin

White Volta River Basin

Oti River Basin

Gauging station

Gauging station

Data source: Basin limits derived from elevation data using ArcGIS hydrology tools and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Hydrography and major basins

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

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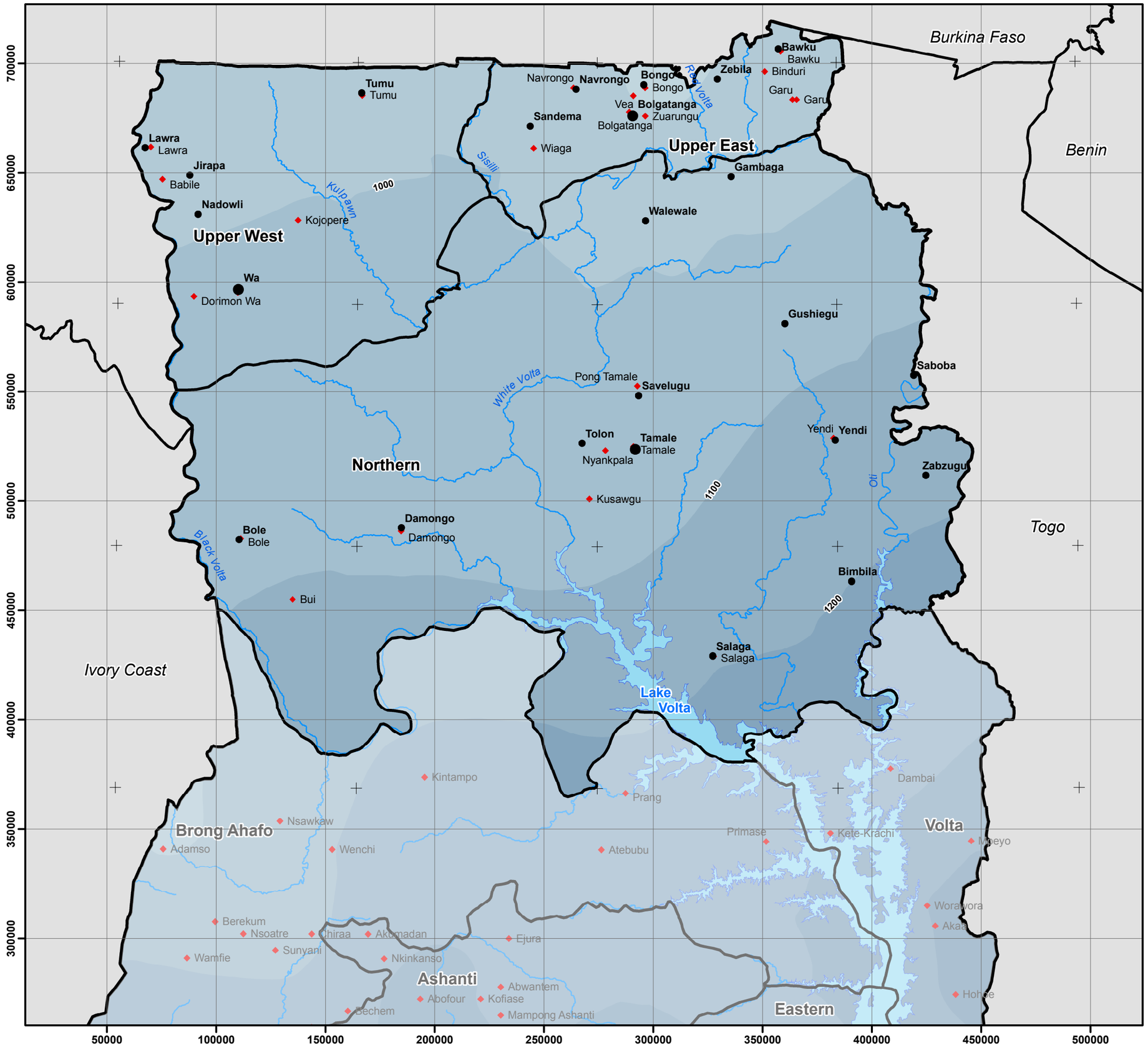

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Meteorological stations

- Meteorological station

Rainfall

- < 800 mm/y
- 800 - 900 mm/y
- 900 - 1000 mm/y
- 1000 - 1100 mm/y
- 1100 - 1200 mm/y
- 1200 - 1300 mm/y
- 1300 - 1400 mm/y
- 1400 - 1500 mm/y

(N.B.: rainfall values were interpolated by ordinary kriging using monthly data from 141 meteorological stations for the 1971-2007 period)

Data source: Rainfall data obtained from the Ghana Meteorological Services Department and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Average annual rainfall pattern

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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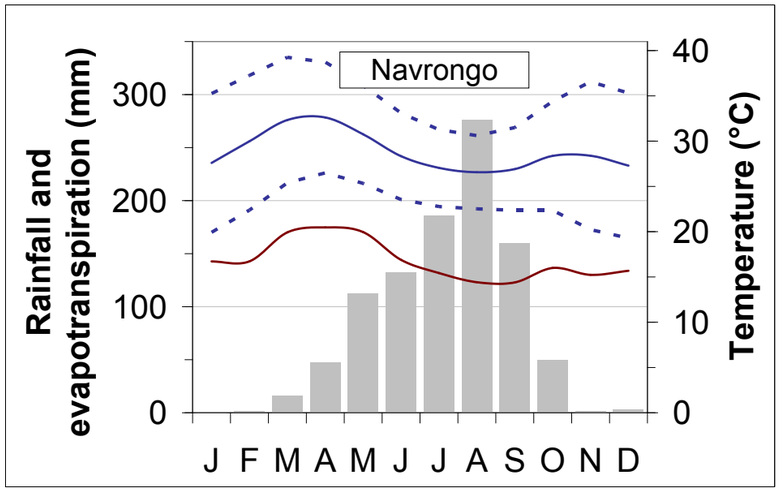

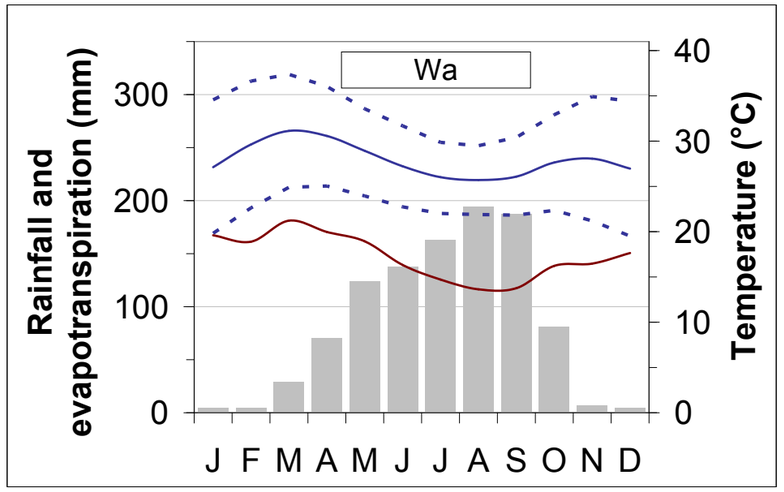

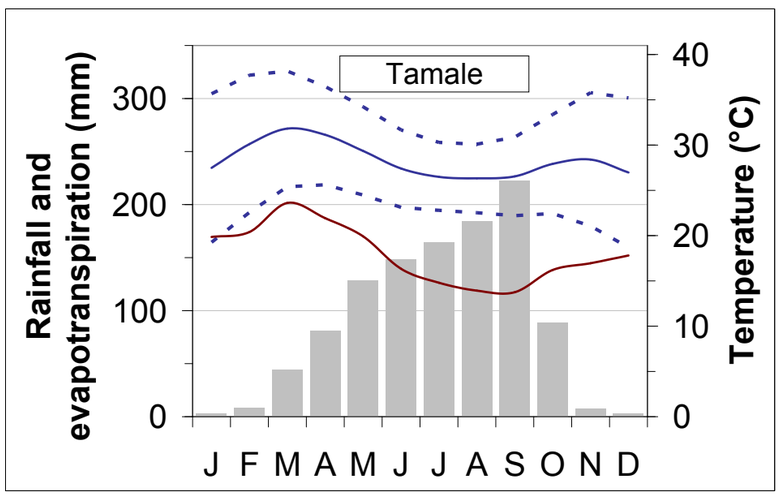

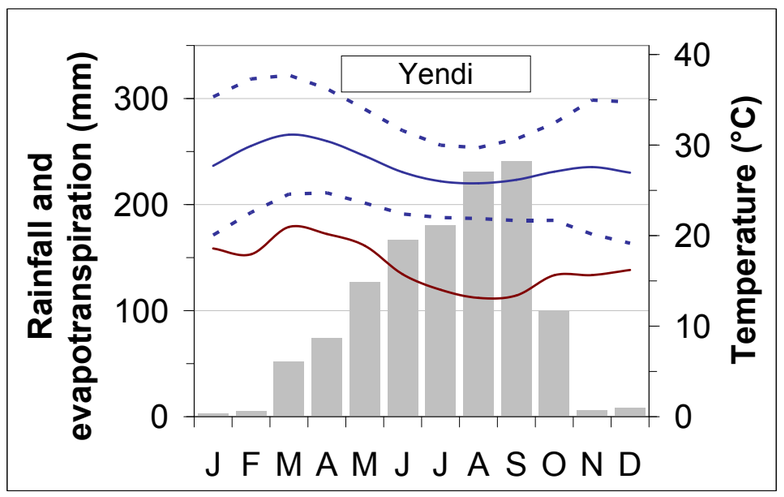

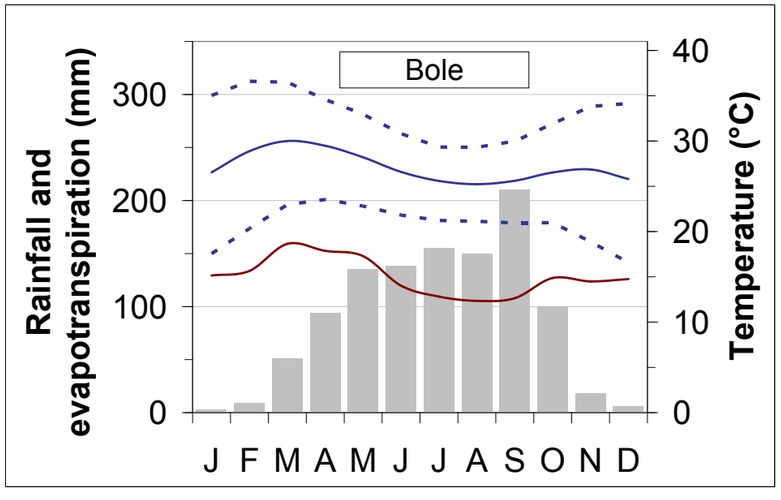

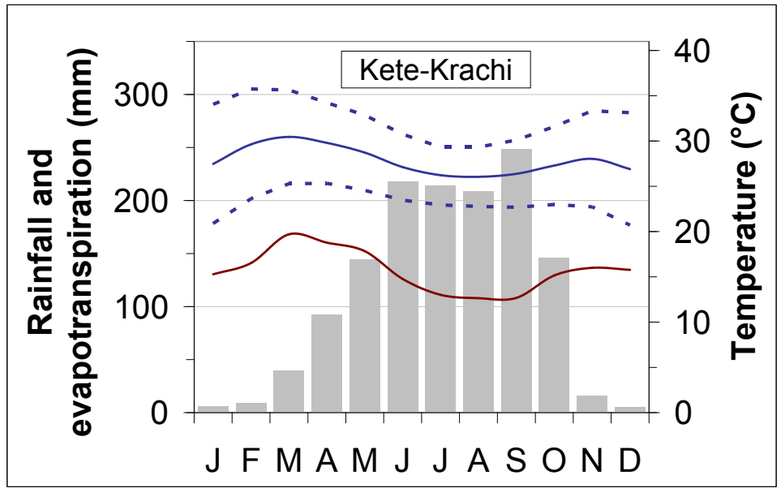

Climate variables

- Rainfall
- Evapotranspiration
- Temperature (average)
- Temperature (min. and max.)

Data source: Monthly rainfall data (1961-2005) obtained from the Ghana Meteorological Services Department.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Average monthly profiles for selected climates variables

Project

Hydrogeological Assessment of the Northern Regions of Ghana

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Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

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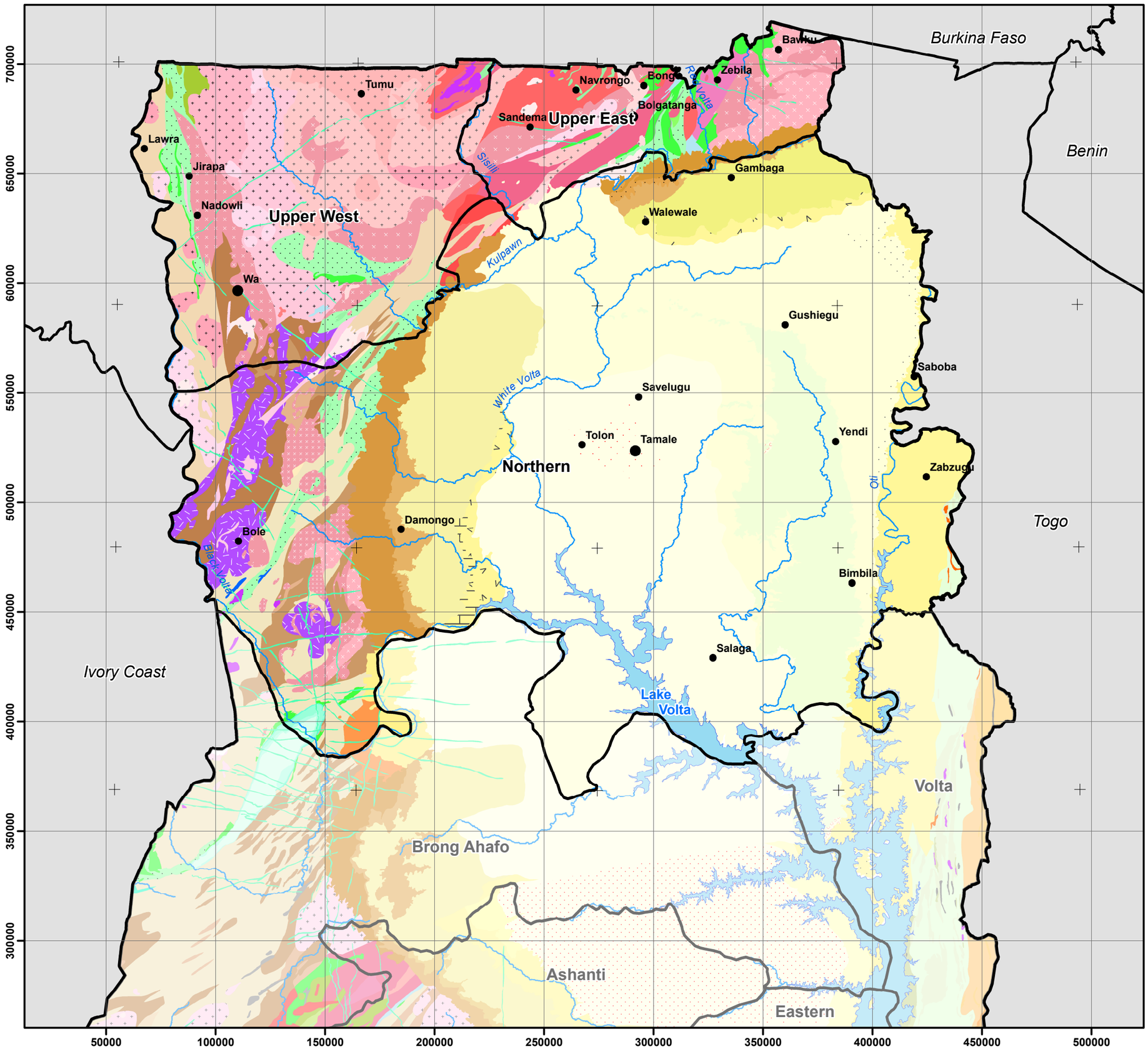
Geology and soil



Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

(see detailed legend on following page)

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Surficial geology

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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File name: atl_geology.mxd

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Surficial geology legend

Precambrian Basement

Buem Structural Unit

- busp — Gabbro, serpentinite (includes some mafic/ultramafic intrusions of possible Ordivician age)
- bub — Alkali basaltic flow and subvolcanic rock, volcanic agglomerates, minor trachyte
- butz — Volcaniclastic sandstone
- buch — Chert
- bufe — Banded hematite-chert rock/ironstone, Fe-rich siltstone and minor Fe-rich sandstone
- bush — Shale, siltstone, locally phyllite or phyllonite, minor sandstone and quartzite
- bust — Quartzose and minor feldspathic sandstone, locally quartzite, minor siltstone, shale, phyllite and limestone

Togo Structural Unit

Kpassa Complex

- tdch — Chert
- tdph — Phyllite, minor sandstone and quartzite
- tdsq — Quartzitic sandstone, quartzite, minor phyllite

Atacora Complex

- tpsp — Serpentinite, talc schist
- tpms — Mica schist (+/- chlorite), minor quartzite
- tpq — Quartzite, minor mica schist

Tarkwaian Group

Ashanti Belt Area

- tadg — Dolerite, micro-gabbro, micro-diorite (dyke or sill)
- tah — Sandstone ('Huni Fm')
- tat — Argillite, siltstone, tuff ('Tarkwa phyllite Fm')
- tab — Conglomerate, mature, quartz pebble and quartzose sandstone ('Banket Fm')
- tak — Conglomerate, immature ('Kawere Fm')
- ta — Detrital sediment, undifferentiated

Bui-Banda Belt Area

- tbt — Sandstone, minor siltstone ('Tombe Fm')
- tby — Conglomerate, interbedded sandstone ('Nyanchulo Fm')
- tbk — Sandstone, minor conglomerate ('Kane Fm', 'Transition Fm')
- tbn — Conglomerate, minor sandstone ('Nuapo Fm')
- tb — Detrital sediment, undifferentiated

Other Belts

- tcq — Detrital sediment, mainly sandstone and conglomerate, undifferentiated

Birimian Supergroup

Sedimentory - Volcano-Sedimentary Group

- bsch — Chert (syn- or epigenetic)
- bsm — Banded manganese formation
- bsa — Argillitic/pelitic sediment dominant, +/- kerogene ('graphite')
- bsw — Wacke sediment dominant
- bsv — Volcaniclastic sediment dominant
- bs — Sediment/volcaniclastic sediment, undifferentiated, locally mica schist

Volcano - Plutonic Group Volcanic Rocks

- bvf — Dacitic to rhyolitic flow/subvolcanic rock and minor interbedded volcanoclastics
- bvl — Andesitic flow/subvolcanic rock and minor interbedded volcaniclastics
- bvm — Basaltic flow/subvolcanic rock and minor interbedded volcaniclastics
- bvc — Undifferentiated volcaniclastics, spatially associated andinterbedded with flow rock
- bv — Volcanic flow/subvolcanic rock and minor interbedded volcaniclastics, undifferentiated

Volcano - Plutonic Group Synvolcanic Intrusive Rocks

- gvhg — Hornblende-biotite granite
- gvbp — Biotite granitoid, mostly granodioritic, peraluminous
- gvbm — Biotite granitoid, undifferentiated, mostly granodioritic
- gvhr — Hornblende-biotite granodiorite
- gvht — Hornblende-biotite tonalite
- gvhd — Hornblende-biotite diorite, quartz diorite
- gvh — Hornblende-biotite granitoid, undifferentiated
- gvg — Gabbro, norite
- gvpx — Peridotite, pyroxenite, dunite, +/- serpentinized

Birimian Protoliths Affected by Eburnean Tectono-Metamorphic Overprint

- bmss — Sericite schist, quartz-sericite schist, locally with garnet and/or staurolite
- bmbt — Biotite schist
- bmf — Sediment/volcano-sediment, undifferentiated, upper greenschist to amphibolite facies metamorphic, metasomatized +/- lit-par-lit granitoid intrusions
- bmb — Biotite gneiss, locally migmatitic, and minor biotite schist, +/- garnet, +/- amphibole, in parts gneissose rocks formed at periphery of granitoid plutons
- bmgg — Granitoid gneiss, leucocratic, locally dioritic
- bma — Amphibolite, partly of contact metamorphic origin

Intrusive rocks (granitoids)

Mesozoic

- msd — Mafic dyke, dolerite (inferred from aeromagnetic data, may include pre-Mesozoic dykes, may be concealed by Voltaian cover)

Eburnean Plutonic Suite

- gsmg — Two-mica or muscovite granite and minor granodiorite, locally leucogranite
- gskf — K-feldspar-rich granitoid, mainly granite and monzonite ('Banso'/'Bongo' type)
- gsbg — Biotite granodiorite
- gsbkp — Biotite granite and minor granodiorite, K-feldspar porphyritic
- gsal — Biotite granite (with Archean continental signature) ('Winneba' type)
- gsb — Biotite (+/- hornblende, +/- muscovite) granitoid, undifferentiated
- gsg — Gabbro, norite
- gsht — Hornblende-biotite tonalite, minor granodiorite, minor quartz diorite
- gspx — Ultramafic and minor mafic igneous rock, undifferentiated
- gshd — Hornblende-biotite diorite or quartz diorite
- gsh — Hornblende-biotite granitoid, undifferentiated

'Tamnean' Plutonic Suite

- tmas — Alkali granite, syenite
- tmhz — Hornblende-biotite monzonite to quartz monzonite
- tmbm — Biotite-muscovite granite
- tmhg — Hornblende-biotite granodiorite to quartz monzonite
- tmbz — Biotite-hornblende (monzo)granite, quartz monzodiorite and monzodiorite
- tmbt — Biotite tonalite
- tmht — Hornblende-biotite tonalite, minor granodiorite, minor quartz diorite
- tmmg — Granitoid gneiss, biotite gneiss

Voltaian Supergroup

Obosum Group

- vta — Sandstone, medium grained, arkosic ('Tamale Fm')
- vsa — Conglomerate, poorly sorted, polymictic, large and small pebbles, in arkosic sandstone matrix ('Sang Fm')
- vde — Sandstone, fine to medium grained, arkosic, lithic, subordinately mudstone and siltsone ('Densubon Fm')
- vdk — Sandstone, very poorly sorted, lithic, arkosic, and polymictic conglomerate ('Dunkro Fm')
- vos — Mudstone, siltstone, sandstone, undifferentiated (undifferentiated 'Obosum Group')

Oti-Pendjari Group

- vby — Sandstone, medium grained, arkosic, lithic, weakly micaceous, with mudstone flakes ('Bunya Fm')
- vcp — Sandstone, medium grained, micaceous, arkosic, lithic ('Chereponi Fm')
- vba — Mudstone and siltstone,weakly micaceous, with thin beds of arkosic, lithic sandstone ('Bimbila Fm')
- vte — Sandstone, thinly bedded to laminated and cross-laminated, quartzose, locally coarse grained ('Tease Fm')
- vej — Sandstone, thinly bedded, fine to medium grained, quartzose ('Ejura Fm')
- vaf — Mudstone and siltstone, micaceous, sporadic limestone beds ('Afram Fm')
- vak — Sandstone, pebbly, arkosic and polymictic, large-pebbly conglomeratic ('Akroso Fm')
- vdb — Tuff, siliceous, laminated, vitric, interbedded with fine grained, laminated, arkosic sandstone ('Darebe Mb' of 'Kodjari Fm')
- vlp — Limestone, thinly bedded to massive, micritic, sandy, dolomitic towards base ('Buipe Mb' of 'Kodjari Fm'). Basal tillite/conglom.
- vpj — Mudstone, siltstone, sandstone, undifferentiated (undifferentiated 'Oti-Pendjari Group')

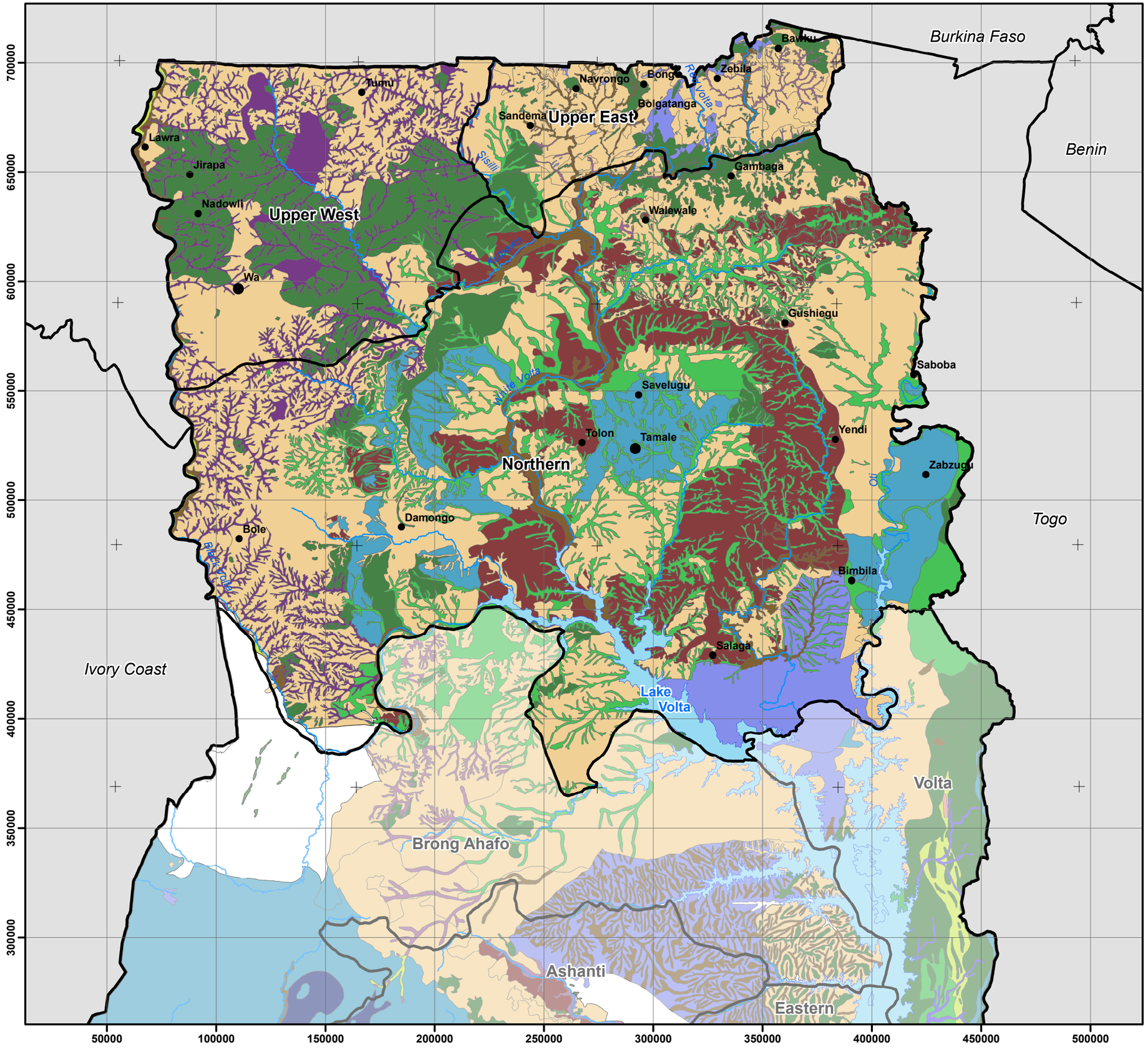
Kwahu-'Morago' Group

Kwahu Group

- van — Sandstone, dune-bedded to cross-bedded, medium grained, arkosic, with mudstone towards base ('Anyaboni Fm')
- vob — Sandstone, thickly bedded to cross-bedded, medium grained, quartzose, with micaceous and finer grained sandstone towards base ('Obocha Fm')
- vat — Sandstone, thickly bedded to cross-bedded, quartzose, locally poorly sorted, becoming finer grained and micaceous towards base ('Abetifi Fm')
- vmp — Sandstone, thickly bedded to cross-bedded, medium grained, quartzose, with micaceous and finer grained sandstone towards base ('Mpraeso Fm')
- vdg — Sandstone, flaggy to laminated, fine to medium grained, micaceous ('Damongo Fm')
- vyb — Sandstone, white, medium grained, cross-bedded, flaggy, quartzose, locally coarse grained ('Yabraso Fm')
- vkw — Mudstone, siltstone and fine grained sandstone, undifferentiated (undifferentaited 'Kwahu Group')

'Morago' Group

- vpn — Sandstone, medium grained, quartzose, cross-bedded ('Panabako Fm')
- vdg — Sandstone, flaggy to laminated, fine to medium grained, micaceous ('Damongo Fm')
- vpg — Mudstone and siltstone, olive green, with sharp-based, thin beds of sandstone ('Poubogou Fm')
- vts — Sandstone, fine grained, locally pebbly ('Tossiego Fm')



Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Soil

- Acrisols
- Alisols
- Arenosols
- Cambisols
- Fluvisols
- Ferralsols
- Gleysols
- Leptosols
- Luvisols
- Lixisols
- Nitosols
- Planosols
- Plinthosols
- Regosols
- Solonchaks
- Solonetz
- Vertisols

Data source: Soil from the Ghana Soil Research Institute and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Soils

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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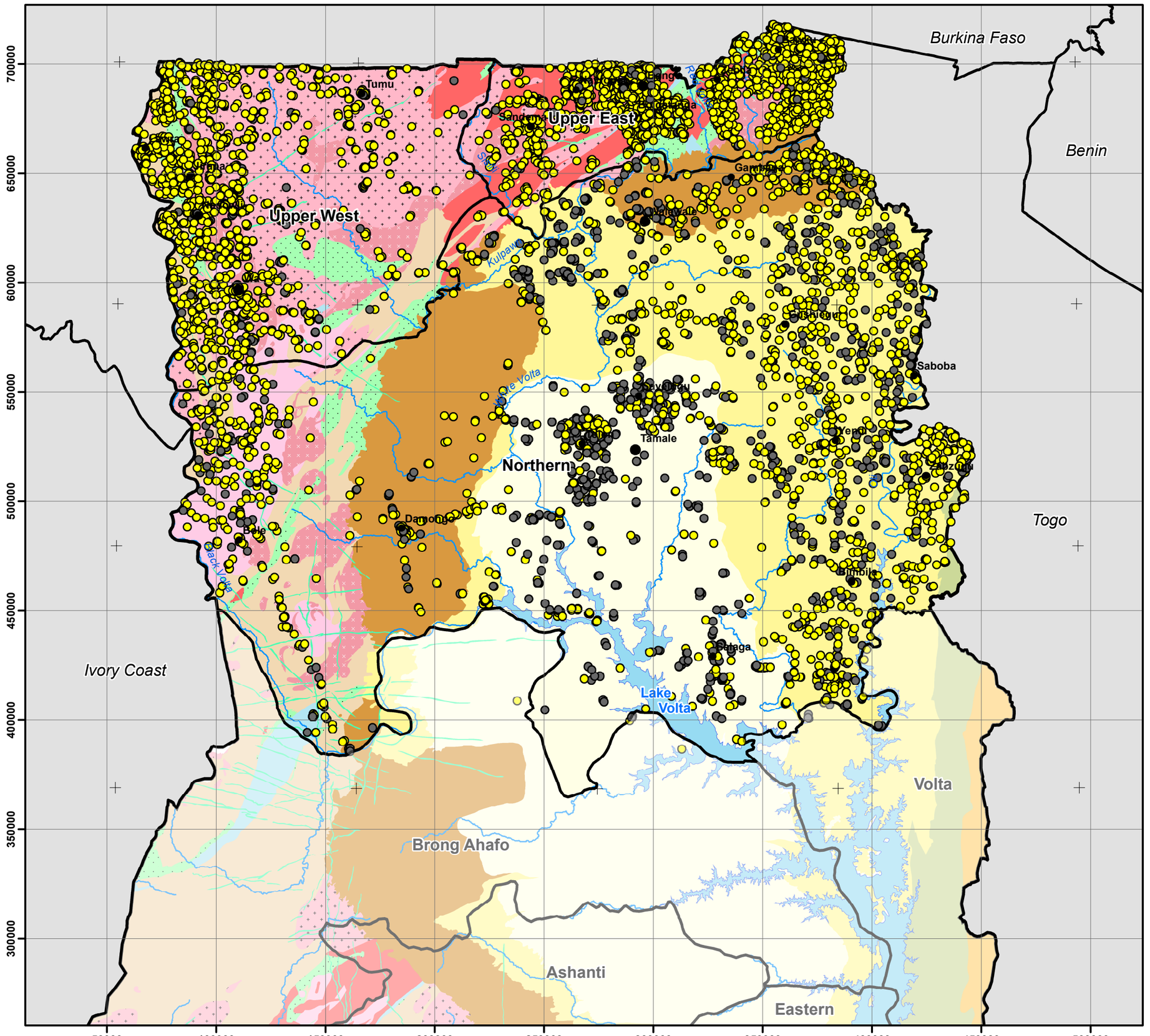
Hydrogeology

Regional hydrogeological conditions



Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology (simplified)

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Well

- Dry or technically negative (1908 wells)
- Successful (5966 wells)

Data source: Well data from the HAP consolidated database, simplified geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Well location

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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File name: atl_well_all.mxd

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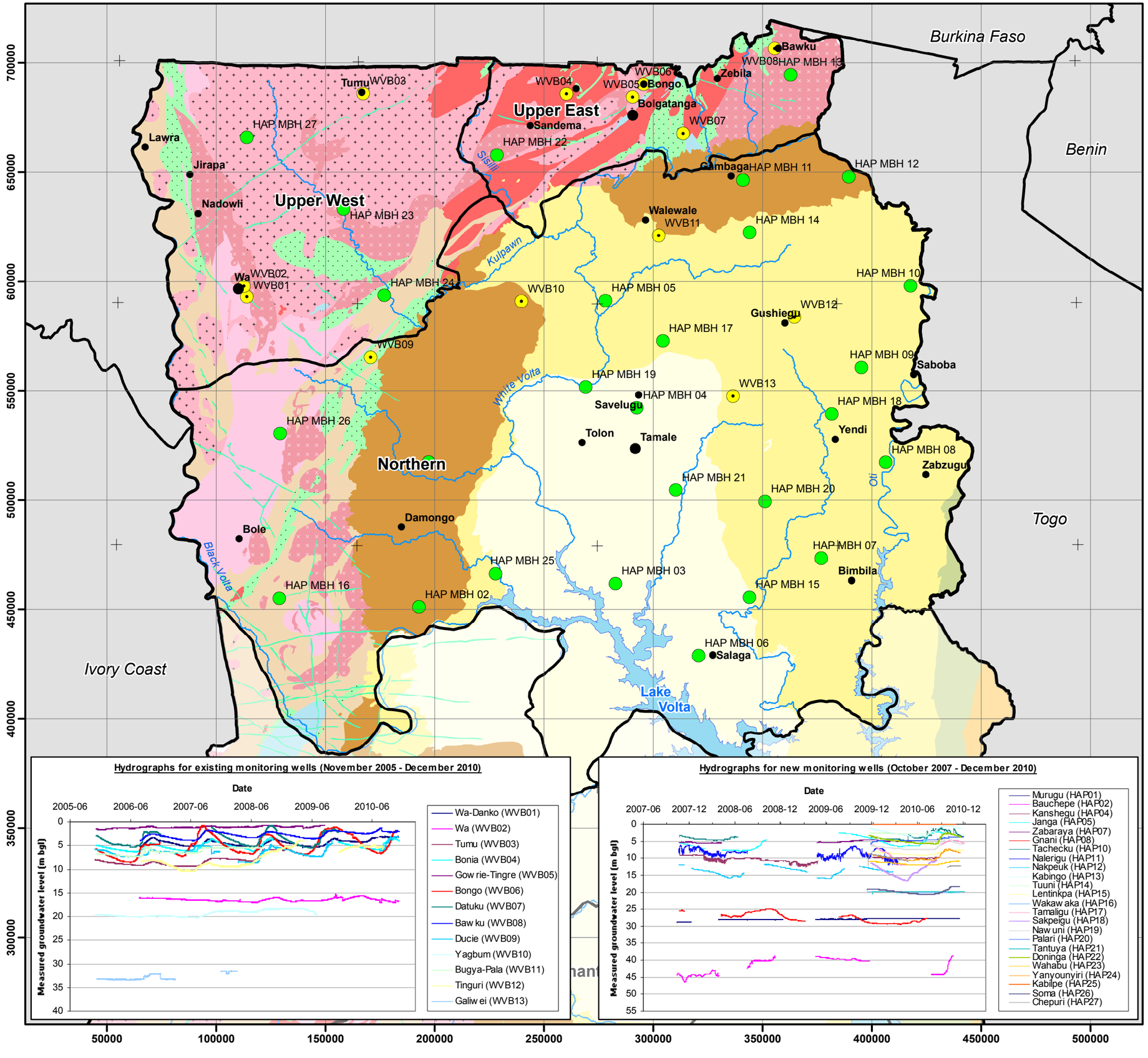

Hydrographs for existing monitoring wells (November 2005 - December 2010)

Hydrographs for new monitoring wells (October 2007 - December 2010)

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology (simplified)

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Monitoring well

- Existing monitoring well (WSSPS2 2005)
- New monitoring well (HAP 2007 and 2009)

Data source: Well data from HAP consolidated database, simplified geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Monitoring well location and hydrographs

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International / INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_well_mw.mxd

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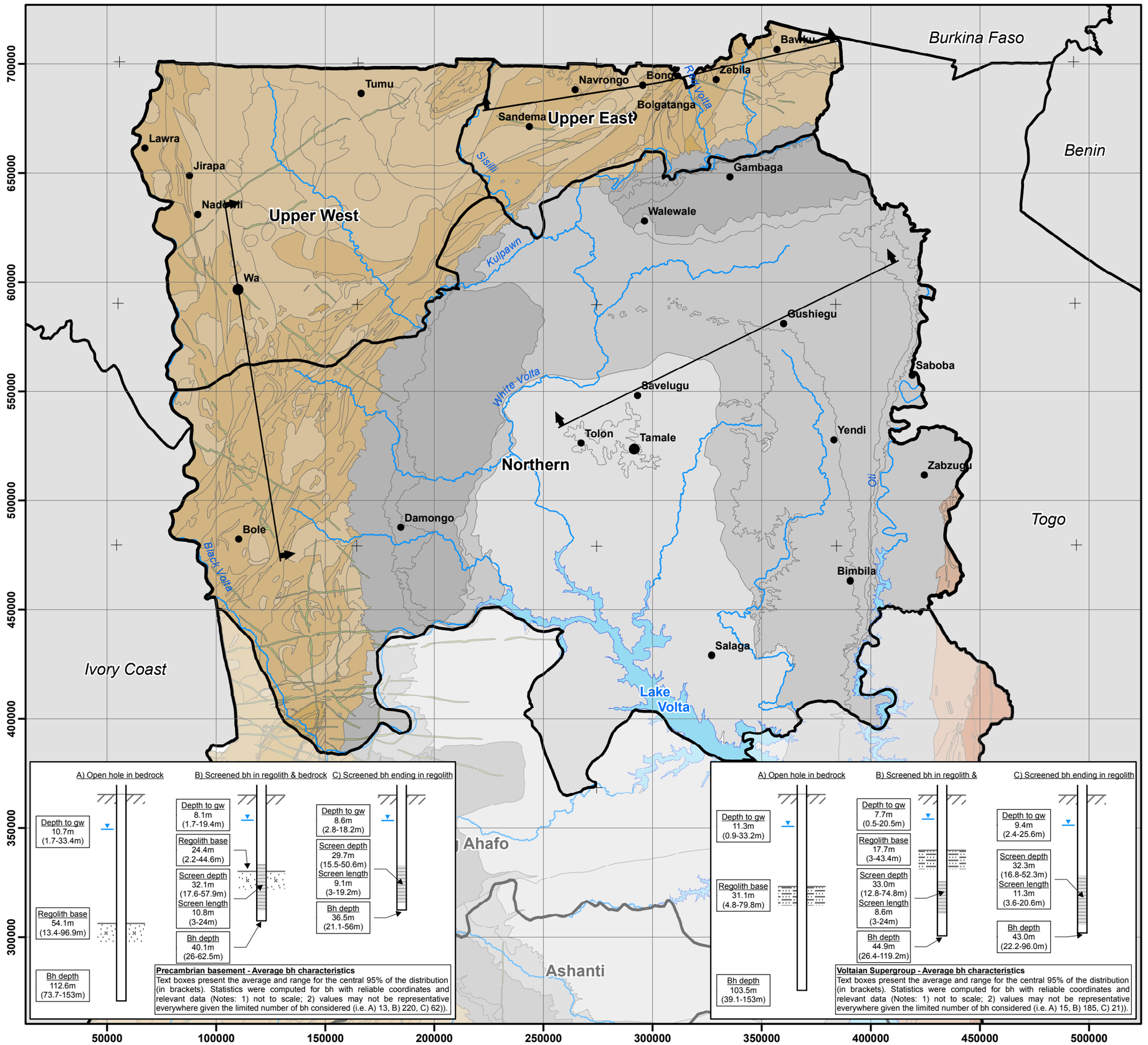

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Hydrogeology

Precambrian basement

- Intrusive rocks (granitoids)
- Birimian Supegroup
- Tarkwaian Group
- Togo Formation (part of mobile belt)
- Buem Formation (part of mobile belt)

Voltaian sedimentary basin

- Obosum Group
- Pendjari-Oti Group
- Kwahu-Morago Group

Cross section

Cross section trace (N.B.: cross sections presented in the following pages)

Data source: Well data from the HAP consolidated database, hydro-geological contexts based on geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Hydrogeological contexts

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International; INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_hydrogeo.mxd

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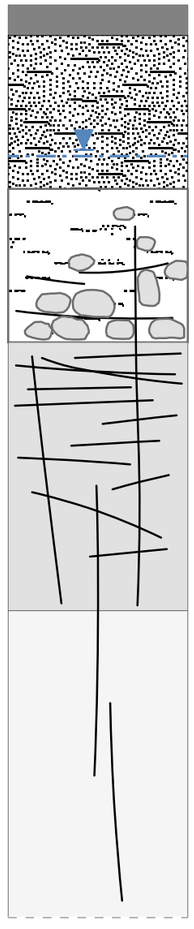
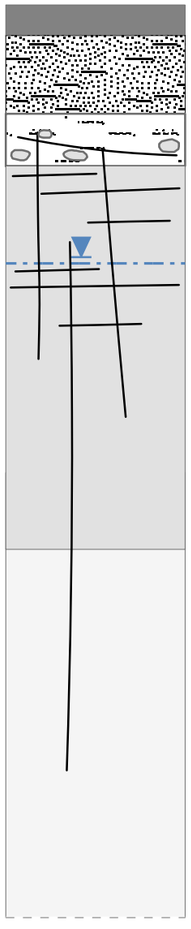
Precambrian basement	
General hydrostratigraphy	**Thickness**
Possible perched aquifer	< 5 m
Leaky semi-confining layer possibly unsaturated locally or during dry season	0-20 m
Leaky aquifer with productive zone in lower part	5-15 m
Leaky fractured aquifer (productive zone mostly associated with sub-horizontal fractures)	15-20 m
Fractured aquifer (variably productive, mostly associated with sub-vertical fractures)	~



General lithology
Residual soil (see note)
Unconsolidated material with little structure preserved
Highly weathered rock (relatively consolidated with structure mostly preserved)
Fractured/weathered rock (moderately to slightly weathered rock with fracture density decreasing downward)
Fresh rock (largely unweathered and variably fractured)



Voltaian sedimentary basin	
Thickness	**General hydrostratigraphy**
< 5 m	Possible perched aquifer
2-15 m	Usually unsaturated zone that can act as a leaky semi-confining layer depending on parent rock and groundwater level
10-80 m	Leaky fractured aquifer (highly variable productive zone depending on lithology, weathering, depth and structure)
~	Fractured aquifer (variably productive, mostly associated with sub-vertical fractures)

Note:
Residial soil includes surface material (transported and *in situ* material often undissociated) and indurated layer (e.g. ferricrete) in some places.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Typical hydrostratigraphic units

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client

Water Resources Commission

Consultant

SNC·LAVALIN International

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Scale		File name
(not to scale)	**SLI 604138**	atl_typic_units.mxd

No.	Date	Description	Drawn	Reviewed
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01	August 2011	Preliminary	M.-A. Carrier	-

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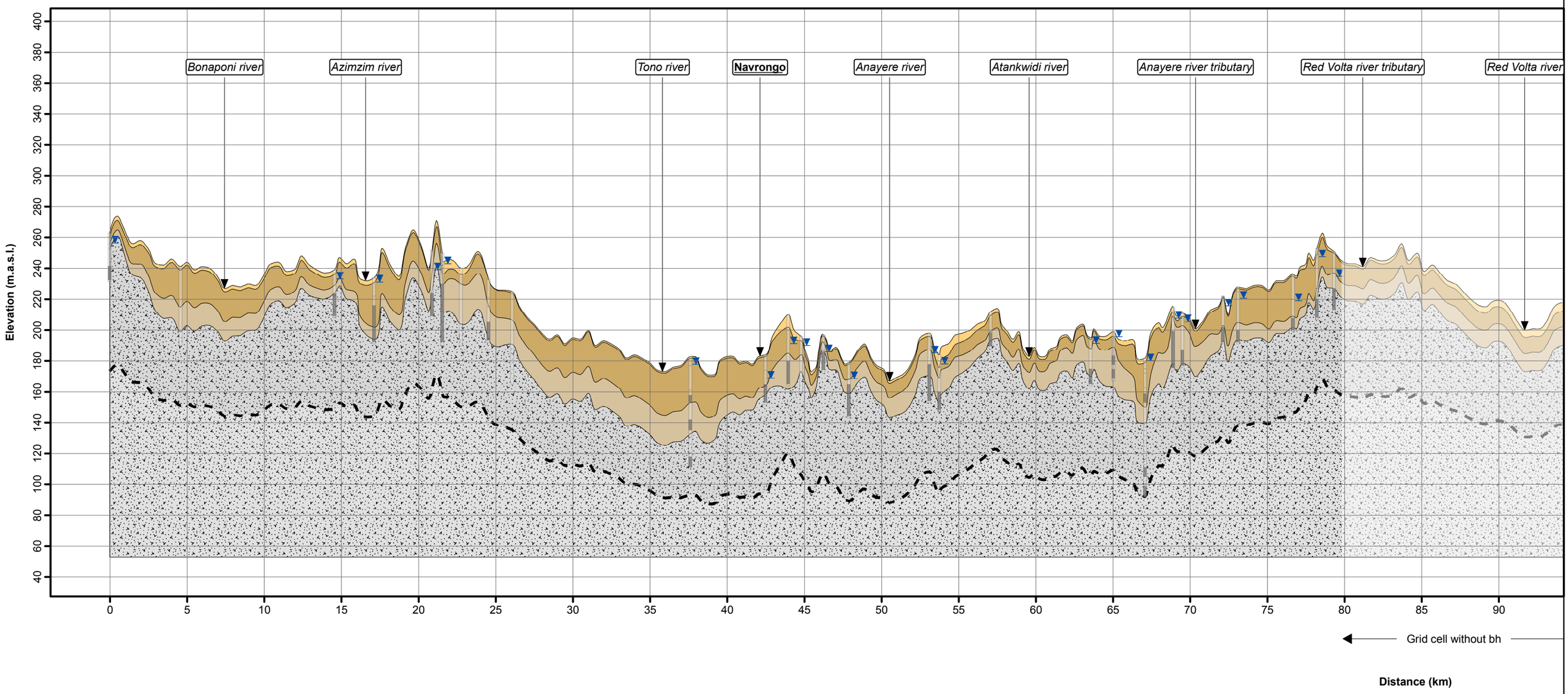
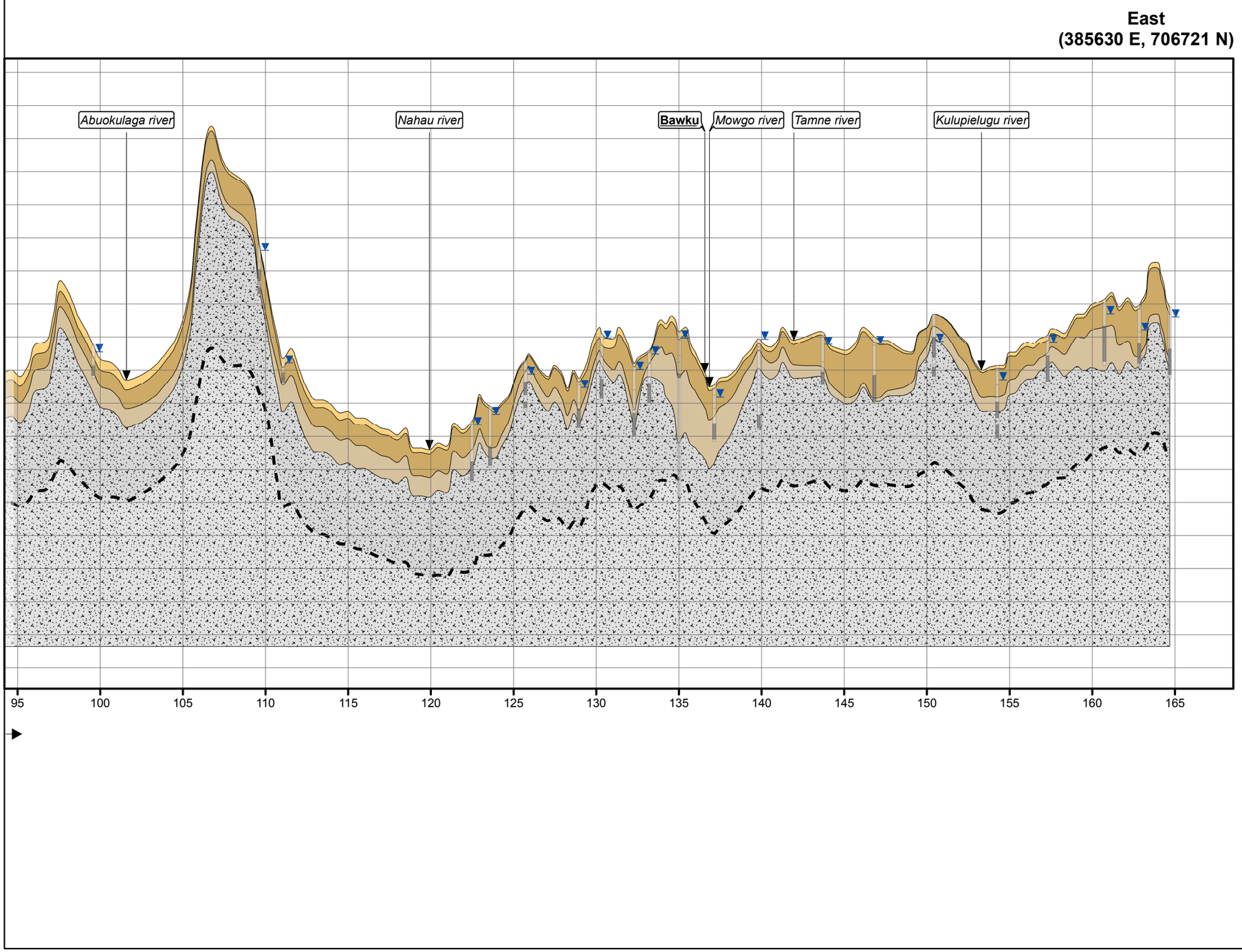
West
(223296 E, 678127 N)





Cross section

- Residual soil
- Upper part of weathered layer
- Lower part of weathered layer
- Fractured rock (N.B.: average thickness based on statistical analysis of deep boreholes)
- Fresh rock
- Static water level (N.B.: only available for some wells)
- Borehole trace (N.B.: screened section shown in dark grey when available)

Data source: Borehole data from HAP consolidated database and all base map layers info from SWERA (N.B.: the relative horizontal distance of boreholes, rivers and communities displayed on cross sections is a projected distance.).

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Hydrostratigraphic cross section Navrongo-Bawku (Precambrian basement)

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client

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Consultant

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Scale

0 2.5 5 7.5 km

Vertical exaggeration: 100x

SLI 604138

File name

atl_xsect_nb.mxd

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01	August 2011	Preliminary	M.-A. Carrier	-

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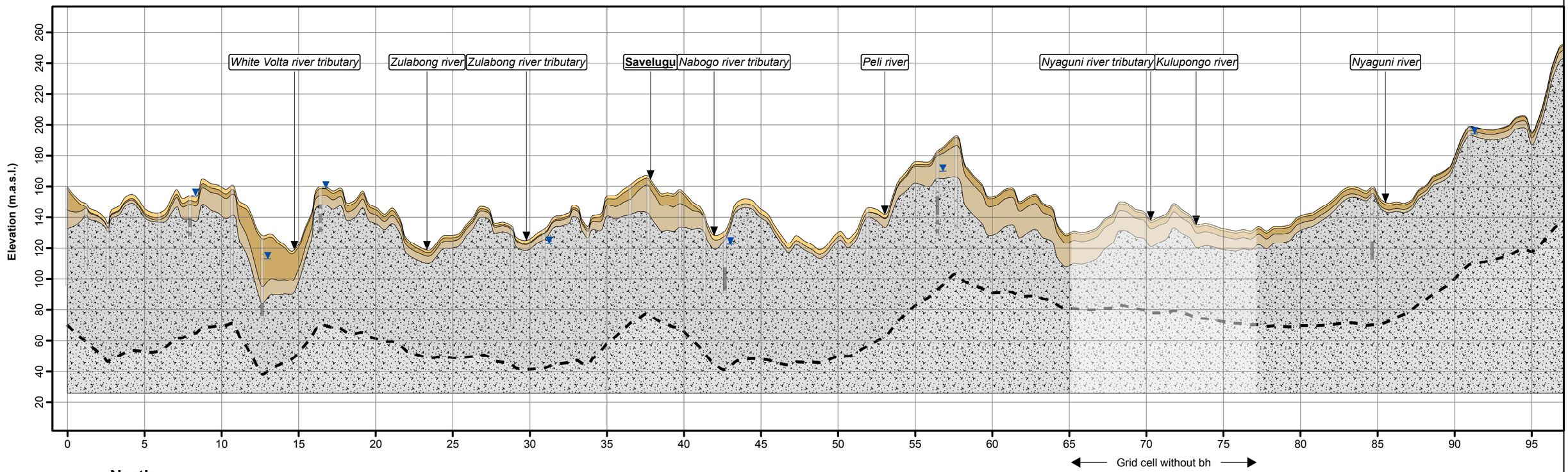
West
(258005 E, 534195 N)



North
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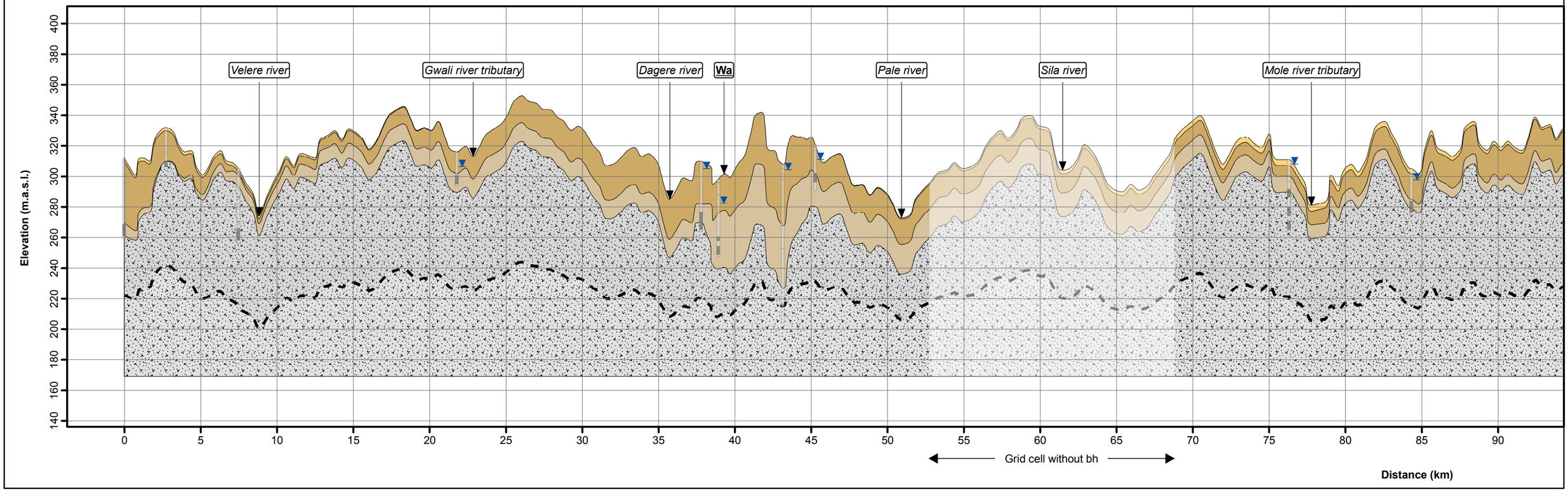
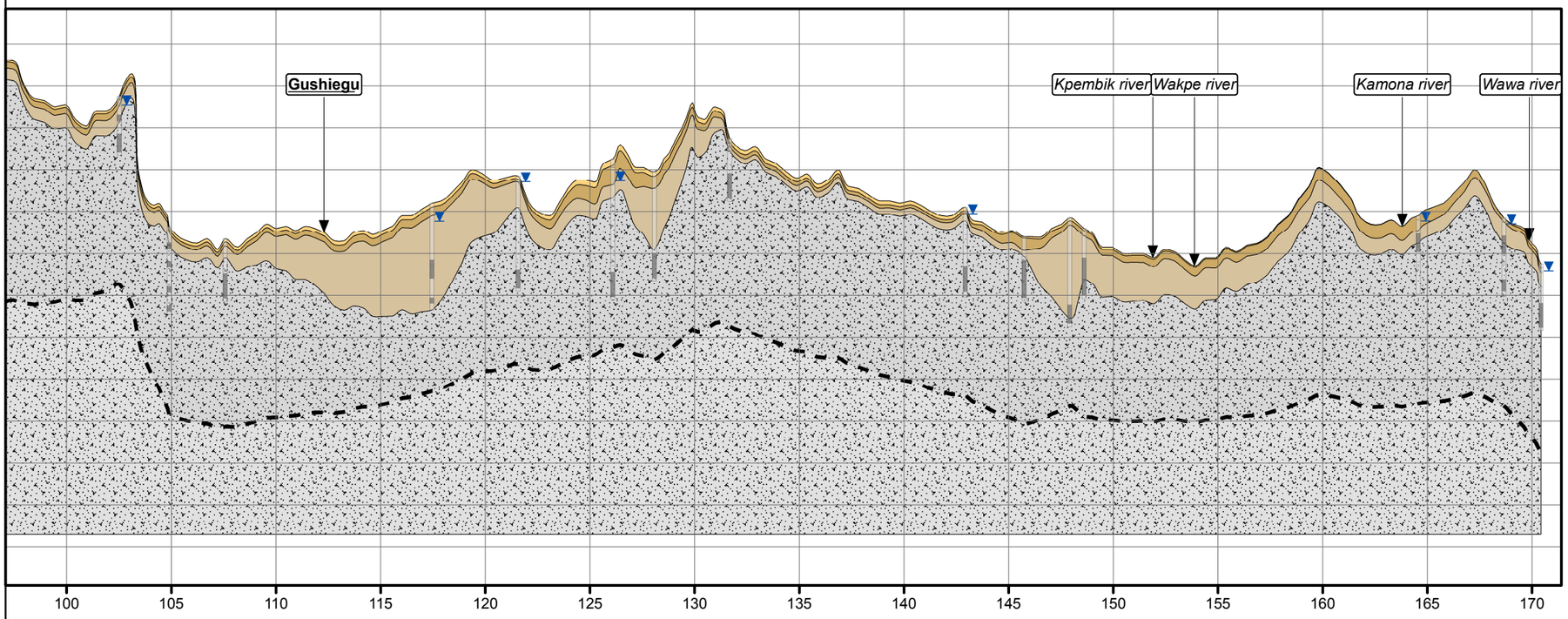
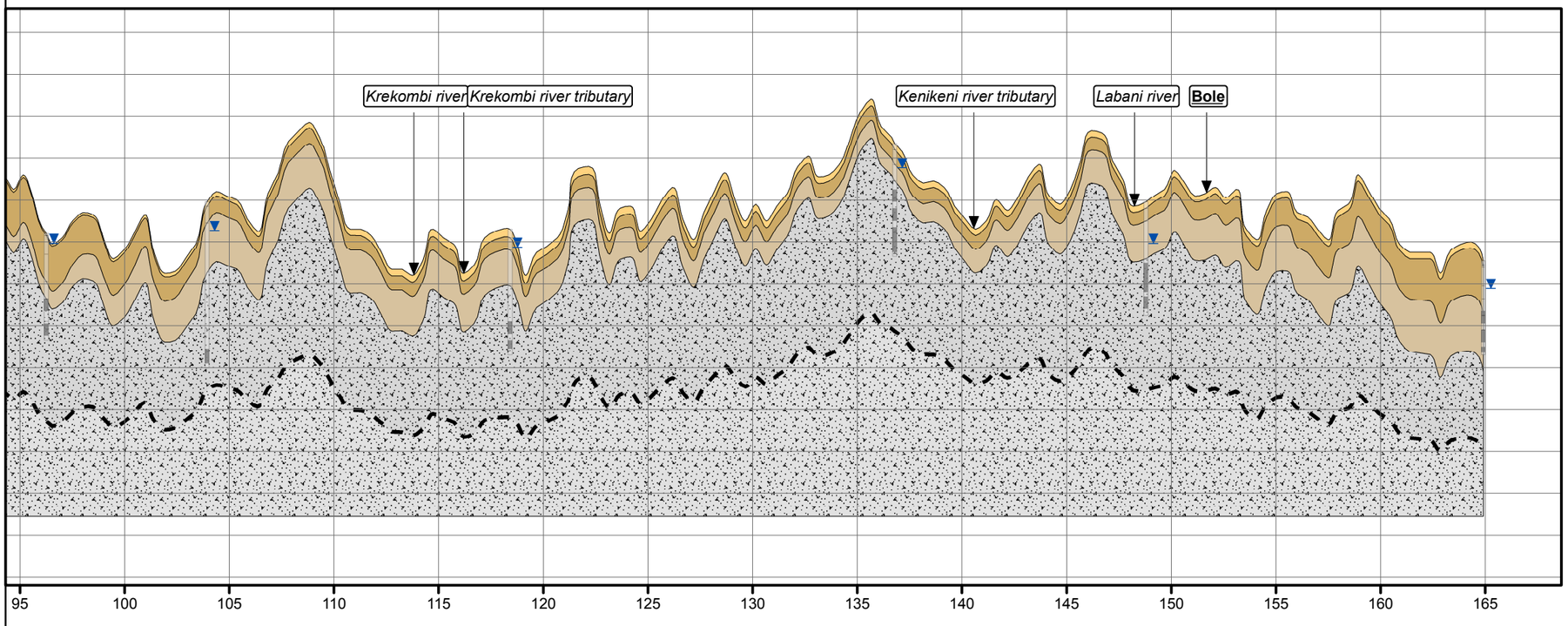


East
(409109 E, 613086 N)



South
(132046 E, 473532 N)



Cross section

- Residual soil
- Upper part of weathered layer
- Lower part of weathered layer
- Fractured rock (N.B.: average thickness based on statistical analysis of deep boreholes)
- Fresh rock
- Static water level (N.B.: only available for some wells)
- Borehole trace (N.B.: screened section shown in dark grey when available)

Data source: Borehole data from HAP consolidated database and all base map layers info from SWERA (N.B.: the relative horizontal distance of boreholes, rivers and communities displayed on cross sections is a projected distance.).

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title
Hydrostratigraphic cross sections Savelugu-Gushiegu (Voltaian) and Wa-Bole (Precambrian basement)

Project
Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client
Water Resources Commission

Consultant
SNC-LAVALIN International
INRS Université d'avant-garde

Scale
0 2.5 5 7.5 km
Vertical exaggeration: 100x

SLI 604138

File name
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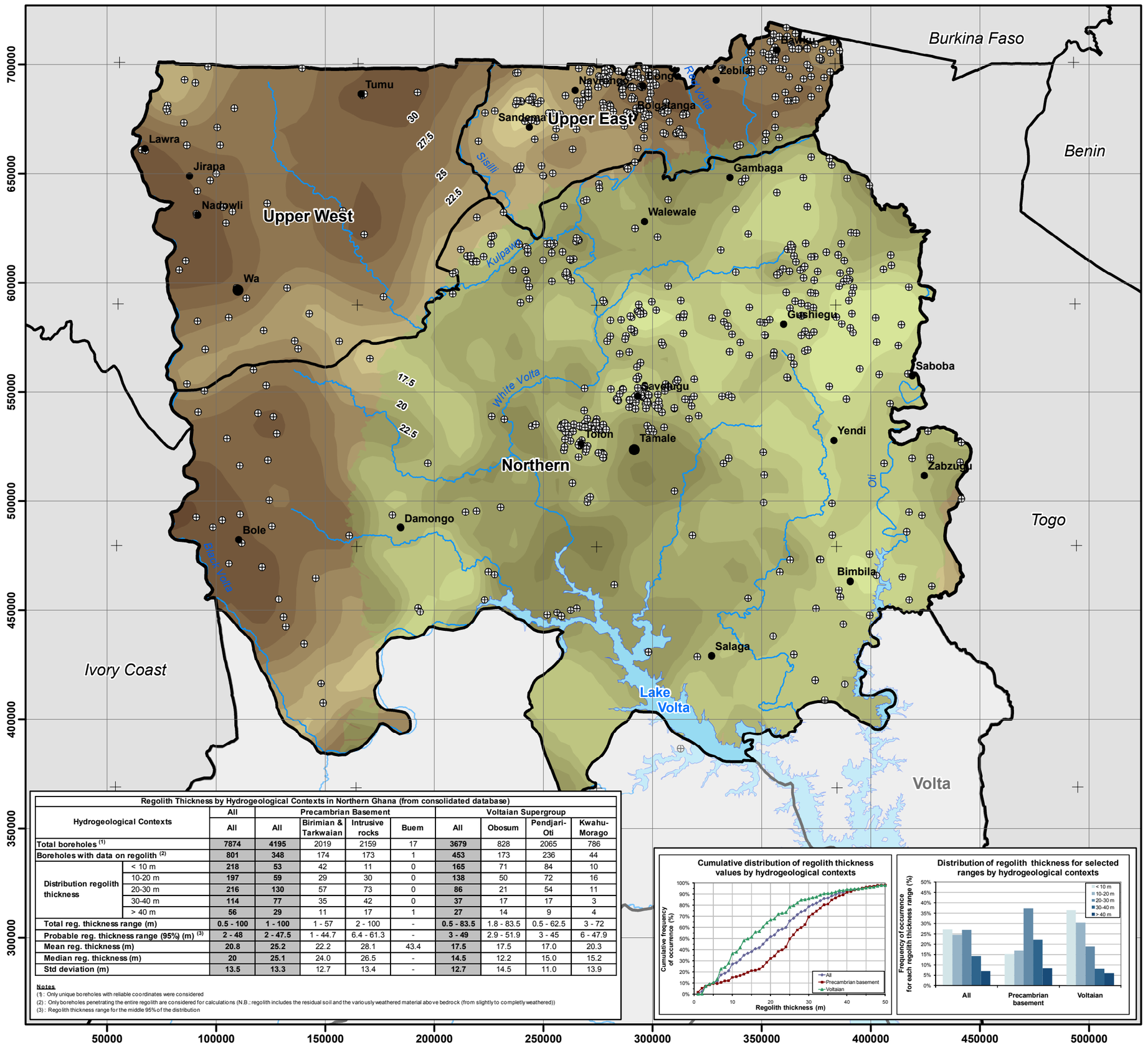

Regolith Thickness by Hydrogeological Contexts in Northern Ghana (from consolidated database)										
Hydrogeological Contexts		All	Precambrian Basement				Voltaian Supergroup			
		All	All	Birimian & Tarkwaian	Intrusive rocks	Buem	All	Obosum	Pendjari-Oti	Kwahu-Morago
Total boreholes (1)		7874	4195	2019	2159	17	3679	828	2065	786
Boreholes with data on regolith (2)		801	348	174	173	1	453	173	236	44
Distribution regolith thickness	< 10 m	218	53	42	11	0	165	71	84	10
	10-20 m	197	59	29	30	0	138	50	72	16
	20-30 m	216	130	57	73	0	86	21	54	11
	30-40 m	114	77	35	42	0	37	17	17	3
	> 40 m	56	29	11	17	1	27	14	9	4
Total reg. thickness range (m)		0.5 - 100	1 - 100	1 - 57	2 - 100	-	0.5 - 83.5	1.8 - 83.5	0.5 - 62.5	3 - 72
Probable reg. thickness range (95%) (m) (3)		2 - 48	2 - 47.5	1 - 44.7	6.4 - 61.3	-	3 - 49	2.9 - 51.9	3 - 45	6 - 47.9
Mean reg. thickness (m)		20.8	25.2	22.2	28.1	43.4	17.5	17.5	17.0	20.3
Median reg. thickness (m)		20	25.1	24.0	26.5	-	14.5	12.2	15.0	15.2
Std deviation (m)		13.5	13.3	12.7	13.4	-	12.7	14.5	11.0	13.9

Notes
(1) : Only unique boreholes with reliable coordinates were considered
(2) : Only boreholes penetrating the entire regolith are considered for calculations (N.B.: regolith includes the residual soil and the variously weathered material above bedrock (from slightly to completly weathered))
(3) : Regolith thickness range for the middle 95% of the distribution

Limits
- Country
- Regions

Settlements
- Region capitals
- District capitals

Hydrography
- Lakes
- Rivers

Regolith thickness
- < 10 m
- 10 - 12.5 m
- 12.5 - 15 m
- 15 - 17.5 m
- 17.5 - 20 m
- 20 - 22.5 m
- 22.5 - 25 m
- 25 - 27.5 m
- 27.5 -30 m
- > 30 m

(N.B.: 1) Left symbol color (brown scale) represents Precambrian basement and right symbol color (green scale) represents Voltaian). 2) This map is a regional representation of regolith thickness variation in Northern Ghana; given the variability of regolith thicknesses over short distances, it is possible that thicknesses encountered in some areas will differ from those estimated here. 3) Regolith thickness was interpolated by ordinary kriging using only boreholes that end in bedrock; kriging was carried out separately for the two major geological provinces (i.e. Precambrian basement and Voltaian).)

Boreholes
- ⊕ Existing boreholes used for interpolation (total of 801; see table for details)

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Regolith thickness

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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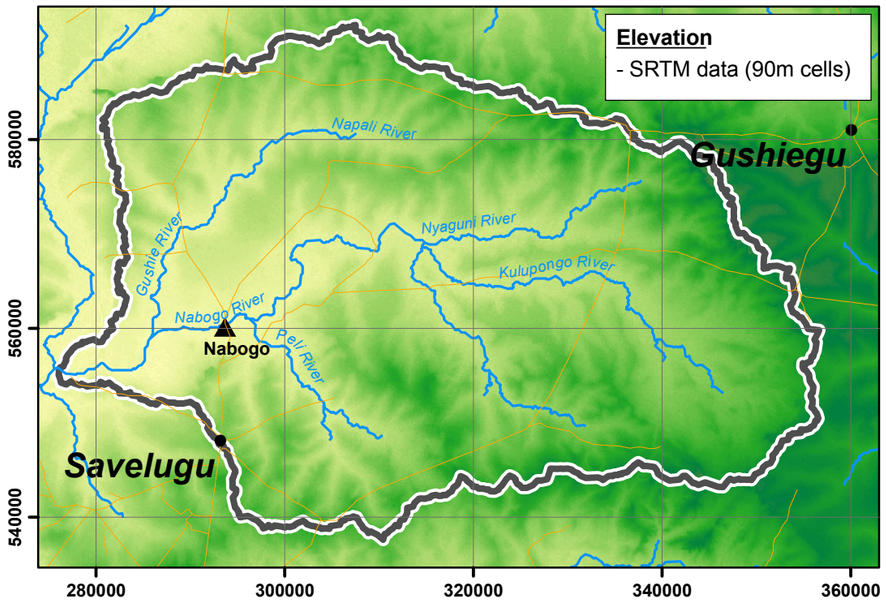

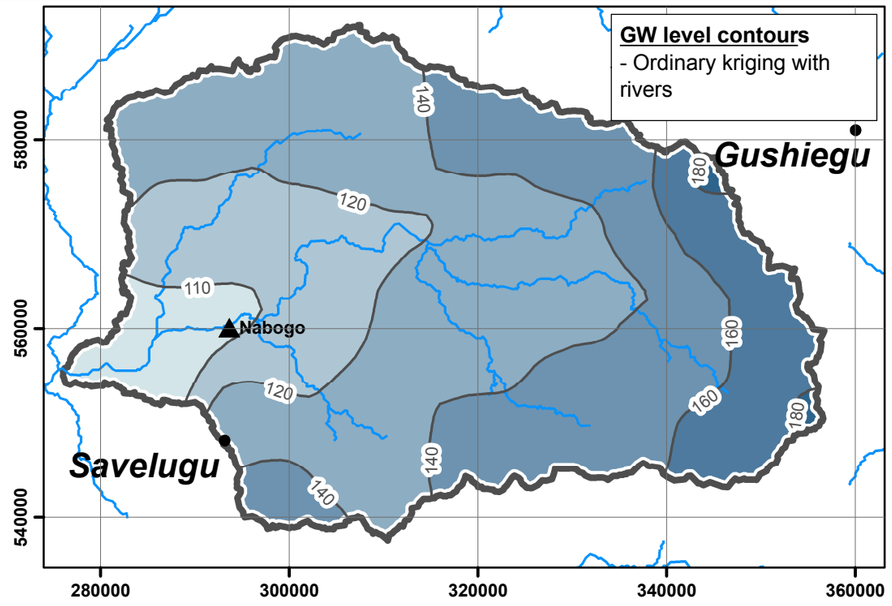

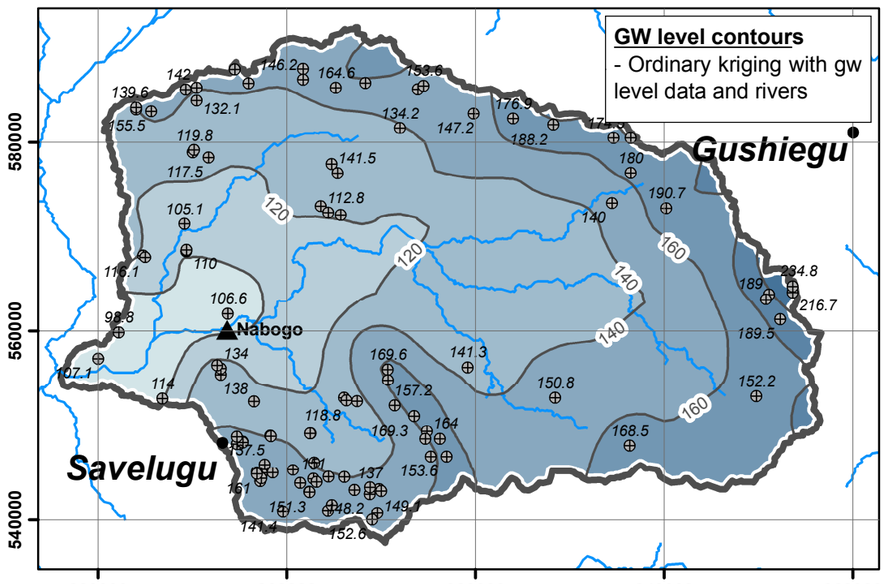

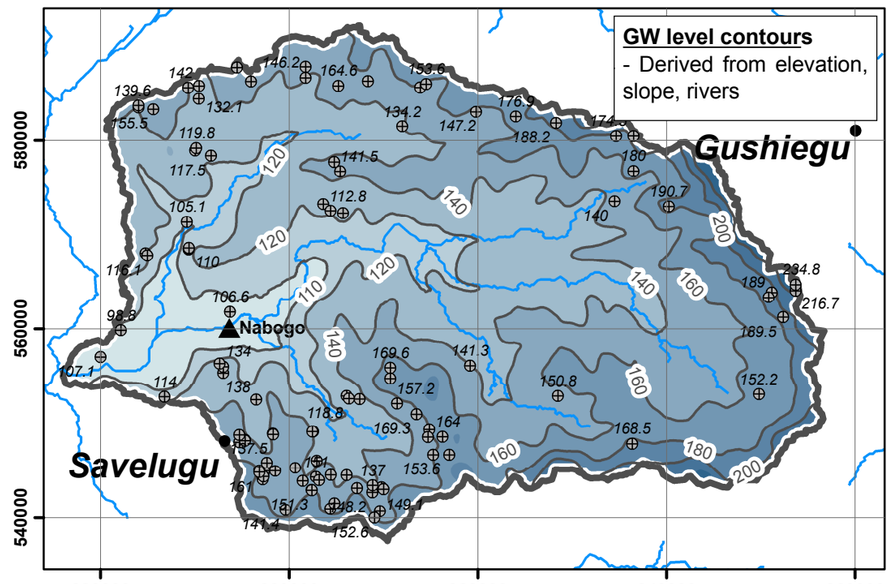

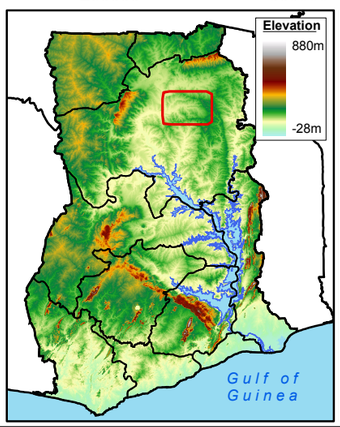

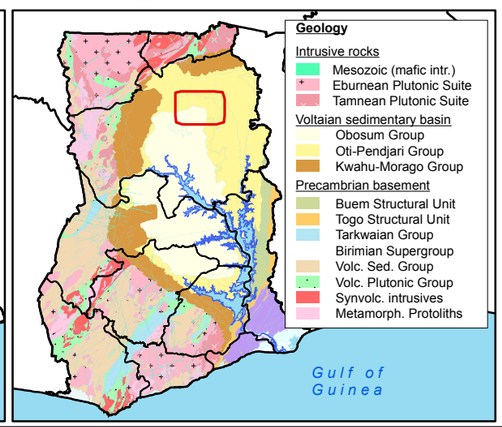

Nabogo basin - General information		
Basin	Location (approx. extent)	-0.98° to -0.25°
		9.53° to 10.02°
	Basin area	2901 km²
	Avg. elevation	152 m
	Elevation range	106 - 269 m
	Avg. slope	0.87°
	Slope range	0° - 10.7°
	Dominant lithology	Shale, mudstone, sandstone
		Pendjari-Oti Gr. (Voltaian)
Available wells inside basin (4)	Number of wells (4)	108
	Avg. well depth	44.0 m
	Well depth range	24 - 99 m
	Avg. depth to gw	9.1 m
	Depth to gw range	2.1 - 32.5 m
	Avg. well yield	102.6 L/min
	Well yield range	7 - 720 L/min
	Avg. specific capacity	102.6 L/min m
	Specific capacity range	0.3 - 720 L/min m
	Avg. regolith thickness	16.5 m
	Regolith thickness range	2.7 - 40 m
	Avg. screen depth (midpoint)	31.8 m
	Screen depth range (midpoint)	2.0 - 68 m
	Avg. screen length	11.3 m

Nabogo basin - Complementary information		
Nearest meteorological station	Station name	Tamale
	Location and elevation (approx.)	-0.85°, 9.5° (173 m)
	Avg. annual precipitation (1)	1040 mm
	Annual precipitation range (1)	791 - 1269 mm
	Avg. annual pot. evapotr. (2)	1944 mm
	Annual pot. evapotr. range (2)	1900 - 1986 mm
	Avg. annual actual evapotr. (2)	862 mm
	Annual actual evapotr. range (2)	694 - 987 mm
	Avg. annual runoff (2)	130 mm
	Annual runoff range (2)	99 - 159 mm
	Avg. annual recharge (2)	48 mm
	Annual recharge range (2)	0 - 123 mm
Gauging station	Station name	Nabogo
	Location and elevation (approx.)	-0.82°, 9.74° (110 m)
	Area upstream of station	2093 km²
	Avg. annual streamflow (3)	10.8 m³/s

Notes:

(1) : Taken from daily climate dataset for 2000-2005 (Meteorological Service Department)

(2) : Evapotr., runoff, recharge at station were estimated from soil moisture balance

(3) : Estimated from streamflow dataset for 1962-2004 period at Nabogo gauging station (Ghana Hydrological Service); avg. only considers years with <30 days of data missing

(4) : Only wells with reliable coord. & data on lithology, gw level or yield are considered

Settlements

- District capitals

Road network

- Roads

Hydrography

- Lakes
- Rivers
- Basin limit

Groundwater level contours

- 140 — Groundwater level contour (m above sea level)

Miscellaneous

- Gauging station
- 189.5 — Well with groundwater level (m above sea level)

Elevation (meters above sealevel)

High : 880

Low : -28

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Potentiometric surface Nabogo basin

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 5 10 20 km

SLI 604138

File name: atl_piezo_nab.mxd

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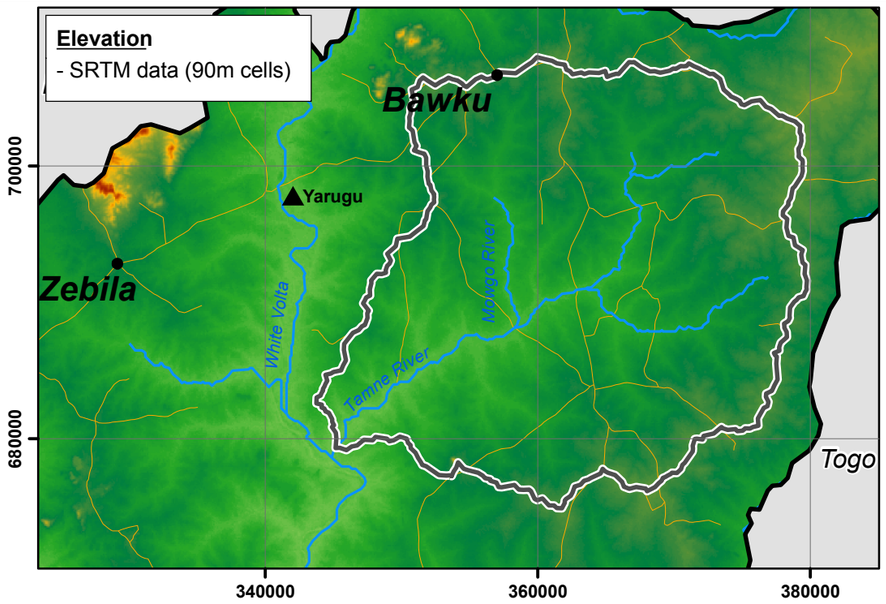

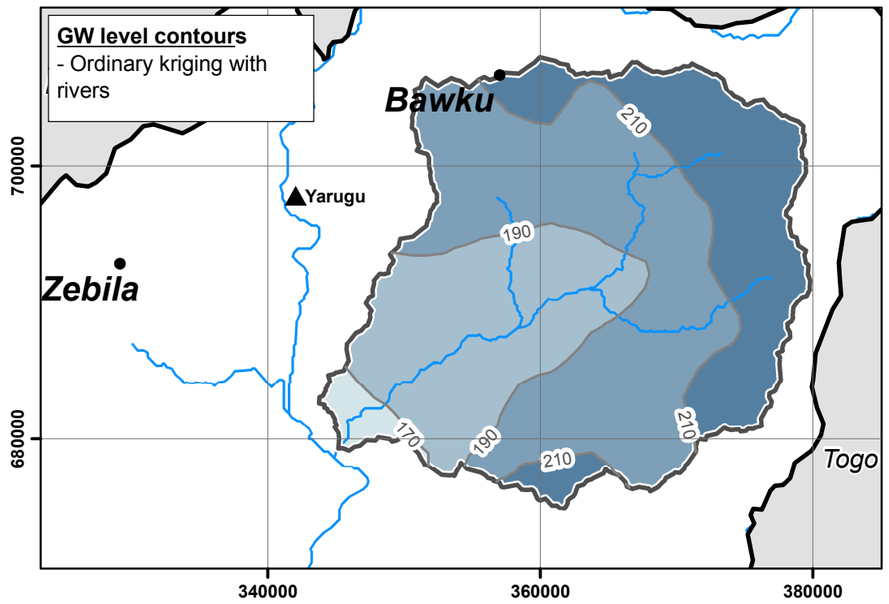

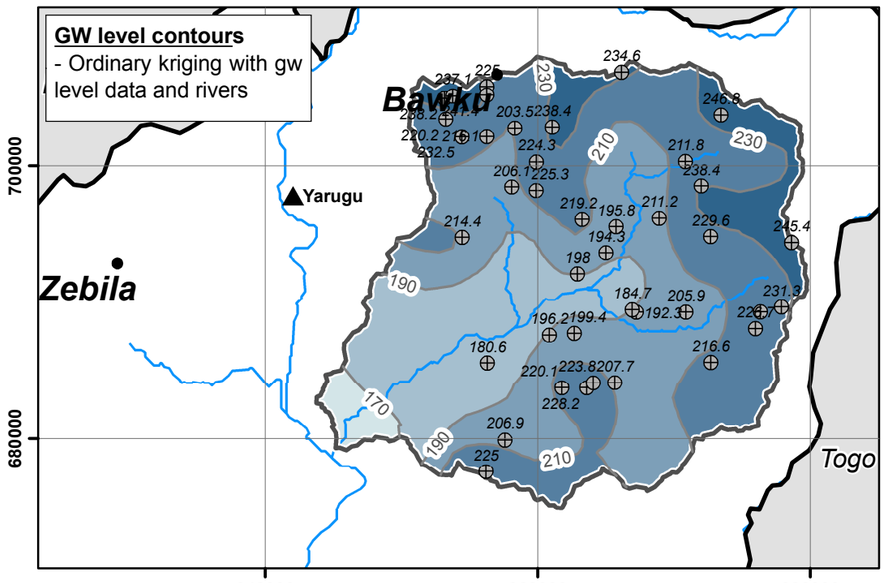

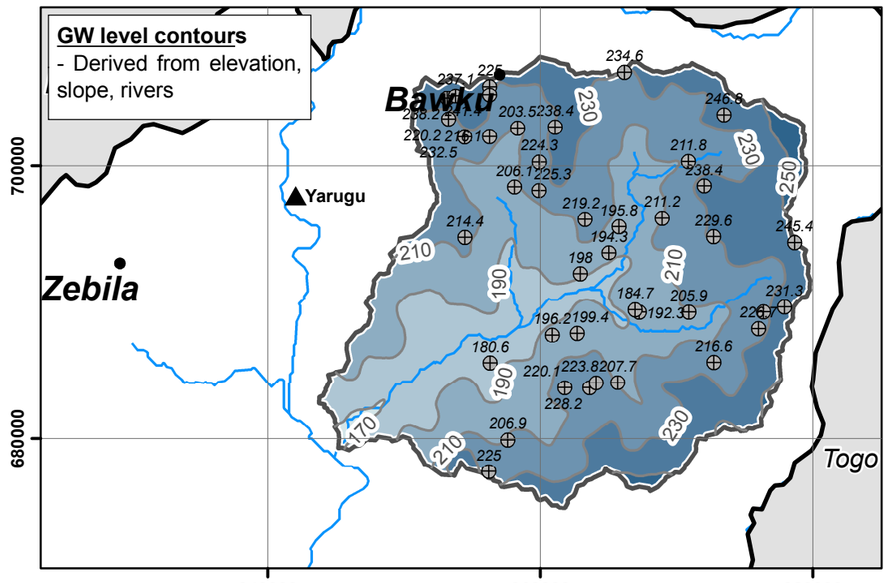

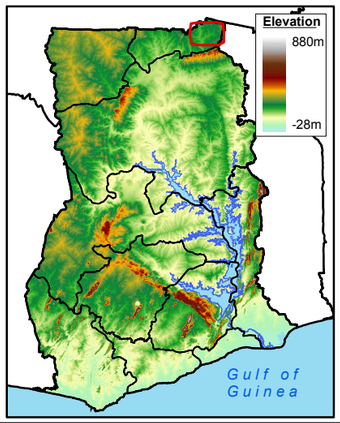

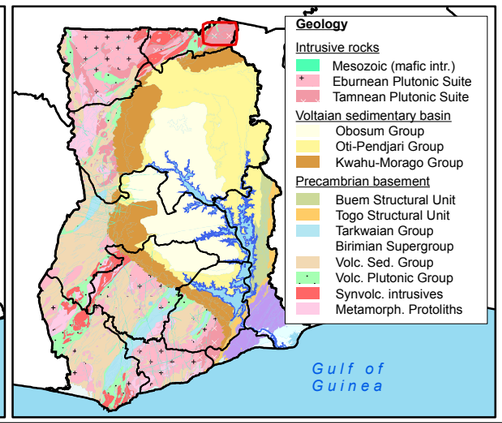

Tamne basin - General information

Basin	Location (approx. extent)	-0.37° to -0.04°
		10.77° to 11.07°
	Basin area	848 km²
	Avg. elevation	219 m
	Elevation range	169 - 348 m
	Avg. slope	1.04°
	Slope range	0° - 21.0°
	Dominant lithology	Cape Coast Granitoids
		Intrusive rocks
Available wells inside basin (5)	Number of wells (5)	40
	Avg. well depth	37.2 m
	Well depth range	22.6 - 55 m
	Avg. depth to gw	6.1 m
	Depth to gw range	0.6 - 12.7 m
	Avg. well yield	46.7 L/min
	Well yield range	2 - 127 L/min
	Avg. specific capacity	7.1 L/min m
	Specific capacity range	1 - 27 L/min m
	Avg. regolith thickness	27.4 m
	Regolith thickness range	7.8 - 37 m
	Avg. screen depth (midpoint)	29.0 m
	Screen depth range (midpoint)	19 - 50 m
	Avg. screen length	11.7 m

Tamne basin - Complementary information

Nearest meteorological station	Station name	Navrongo
	Location and elevation (approx.)	-1.1°, 10.9° (201 m)
	Avg. annual precipitation (1)	963 mm
	Annual precipitation range (1)	750 - 1138 mm
	Avg. annual pot. evapotr. (2)	1968 mm
	Annual pot. evapotr. range (2)	1879 - 2087 mm
	Avg. annual actual evapotr. (2)	758 mm
	Annual actual evapotr. range (2)	657 - 867 mm
	Avg. annual runoff (2)	120 mm
	Annual runoff range (2)	94 - 142 mm
	Avg. annual recharge (2)	84 mm
	Annual recharge range (2)	0 - 162 mm
Nearest gauging station	Station name	Yarugu
	Location and elevation (approx.)	-0.4°, 10.98° (170 m)
	Avg. ann. streamfl. (Tamne) (4)	5.4 m³/s

Notes:

(1) : Taken from daily climate dataset for 2000-2005 (Meteorological Service Department)

(2) : Evapotr., runoff, recharge at station were estimated from soil moisture balance

(3) : Estimated from streamflow dataset for 1966-1990 period (Global Runoff Data Centre)

(4) : Ann. avg. streamflow was estimated from difference between downstream (Pwalugu) and upstream stations (Nangodi & Yarugu), weighted with ratio of basin area (848 km²) over area drained between upstream/downstream stations (4785 km²)

(5) : Only wells with reliable coord. & data on lithology, gw level or yield are considered

Settlements

- District capitals

Road network

- Roads

Hydrography

- Lakes
- Rivers
- Basin limit

Groundwater level contours

- 140 — Groundwater level contour (m above sea level)

Miscellaneous

- Gauging station
- 189.5 — Well with groundwater level (m above sea level)

Elevation (meters above sealevel)

High : 880

Low : -28

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Potentiometric surface Tamne basin

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 2.5 5 10 15 km

SLI 604138

File name: atl_piezo_tam.mxd

No.	Date	Description	Drawn	Reviewed
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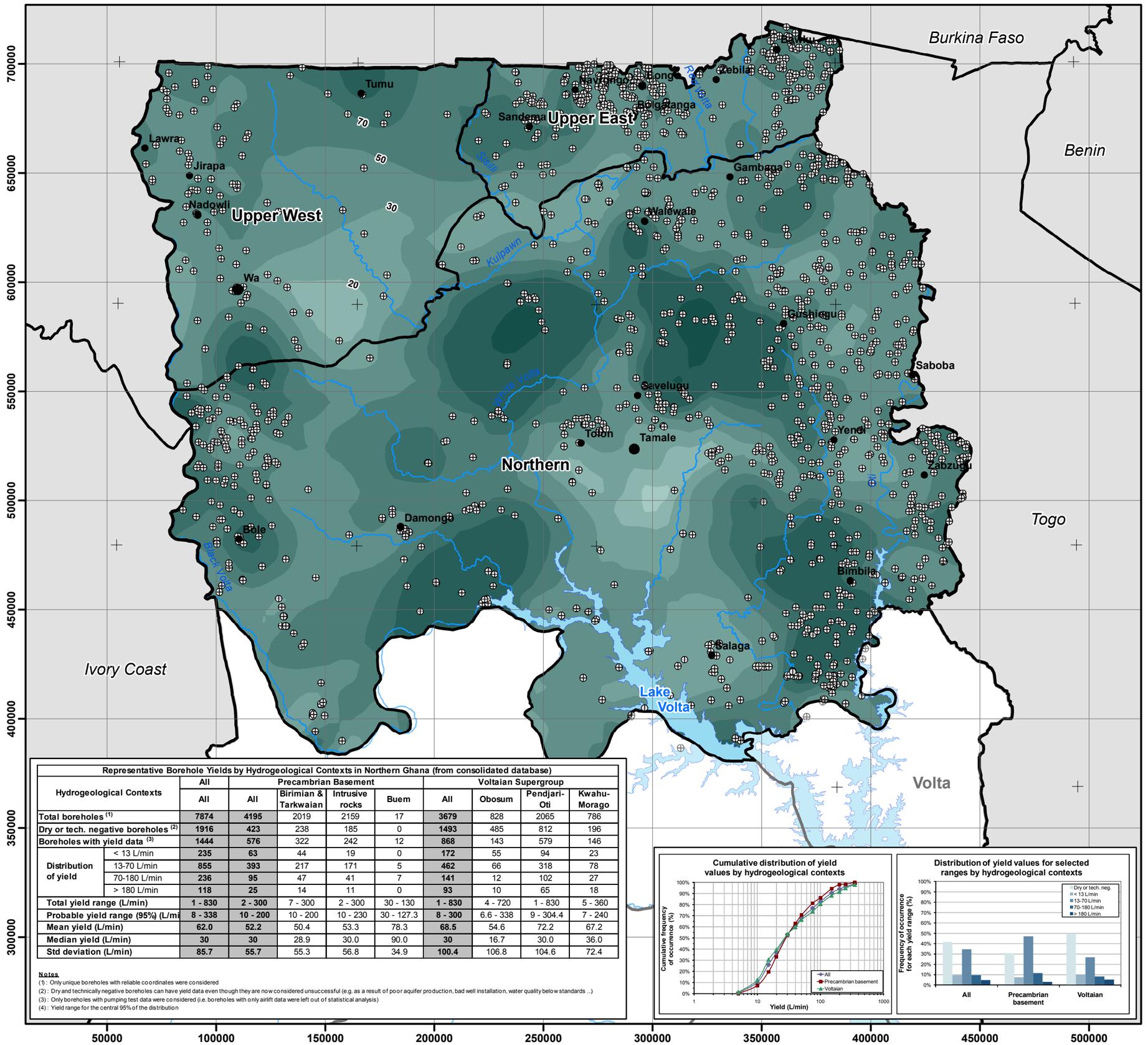
Groundwater production potential



Representative Borehole Yields by Hydrogeological Contexts in Northern Ghana (from consolidated database)										
Hydrogeological Contexts		All	Precambrian Basement				Voltaian Supergroup			
		All	All	Birimian & Tarkwaian	Intrusive rocks	Buem	All	Obosum	Pendjari-Oti	Kwahu-Morago
Total boreholes (1)		7874	4195	2019	2159	17	3679	828	2065	786
Dry or tech. negative boreholes (2)		1916	423	238	185	0	1493	485	812	196
Boreholes with yield data (3)		1444	576	322	242	12	868	143	579	146
Distribution of yield	< 13 L/min	235	63	44	19	0	172	55	94	23
	13-70 L/min	855	393	217	171	5	462	66	318	78
	70-180 L/min	236	95	47	41	7	141	12	102	27
	> 180 L/min	118	25	14	11	0	93	10	65	18
Total yield range (L/min)		1 - 830	2 - 300	7 - 300	2 - 300	30 - 130	1 - 830	4 - 720	1 - 830	5 - 360
Probable yield range (95%) (L/mi		8 - 338	10 - 200	10 - 200	10 - 230	30 - 127.3	8 - 300	6.6 - 338	9 - 304.4	7 - 240
Mean yield (L/min)		62.0	52.2	50.4	53.3	78.3	68.5	54.6	72.2	67.2
Median yield (L/min)		30	30	28.9	30.0	90.0	30	16.7	30.0	36.0
Std deviation (L/min)		85.7	55.7	55.3	56.8	34.9	100.4	106.8	104.6	72.4

Notes
(1) : Only unique boreholes with reliable coordinates were considered
(2) : Dry and technically negative boreholes can have yield data even though they are now considered unsuccessful (e.g. as a result of poor aquifer production, bad well installation, water quality below standards ..)
(3) : Only boreholes with pumping test data were considered (i.e. boreholes with only airlift data were left out of statistical analysis)
(4) : Yield range for the central 95% of the distribution

Limits
- Country
- Regions

Settlements
- Region capitals
- District capitals

Hydrography
- Lakes
- Rivers

Interpolated yield
- < 13 L/min
- 13-20 L/min
- 20-30 L/min
- 30-50 L/min
- 50-70 L/min
- 70-90 L/min
- 90-180 L/min
- > 180 L/min

N.B.: 1) This map is a regional representation of the yield variations in Northern Ghana; it is intended to provide an overview of the regional trends in borehole yield and is therefore not accurate at local scale. 2) Yield was interpolated by ordinary kriging using only boreholes with reliable coordinates for which pumping test data was available.

Boreholes
- ⊕ Existing boreholes used for interpolation (total of 1444; see table for details)

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Well yield

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_yield.mxd

No.	Date	Description	Drawn	Reviewed
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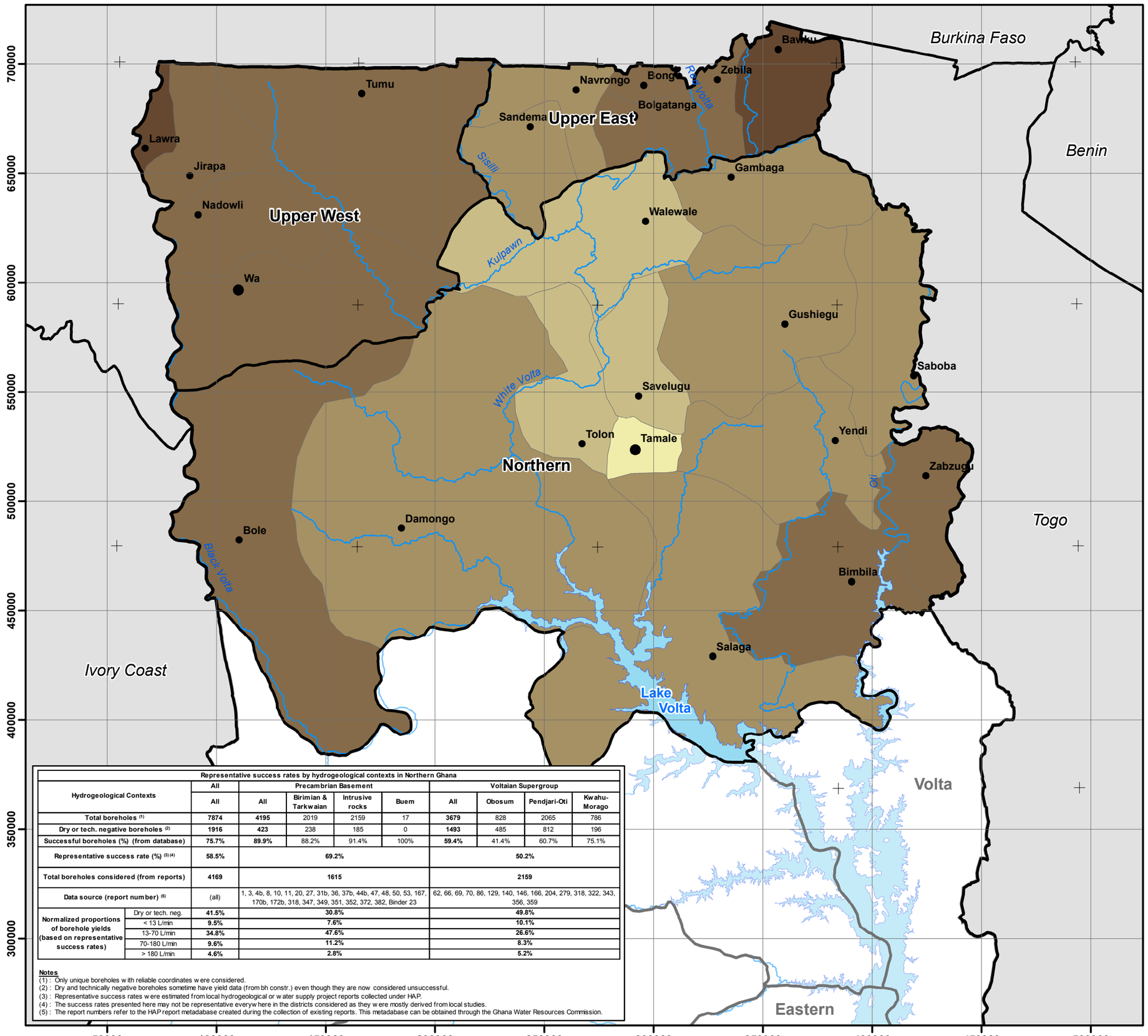

Representative success rates by hydrogeological contexts in Northern Ghana										
Hydrogeological Contexts		All	Precambrian Basement				Voltaian Supergroup			
		All	All	Birimian & Tarkwaian	Intrusive rocks	Buem	All	Obosum	Pendjari-Oti	Kwahu-Morago
Total boreholes (1)		7874	4195	2019	2159	17	3679	828	2065	786
Dry or tech. negative boreholes (2)		1916	423	238	185	0	1493	485	812	196
Successful boreholes (%) (from database)		75.7%	89.9%	88.2%	91.4%	100%	59.4%	41.4%	60.7%	75.1%
Representative success rate (%) (3) (4)		58.5%	69.2%				50.2%			
Total boreholes considered (from reports)		4169	1615				2159			
Data source (report number) (5)		(all)	1, 3, 4b, 8, 10, 11, 20, 27, 31b, 36, 37b, 44b, 47, 48, 50, 53, 167, 170b, 172b, 318, 347, 349, 351, 352, 372, 382, Binder 23				62, 66, 69, 70, 86, 129, 140, 146, 166, 204, 279, 318, 322, 343, 356, 359			
Normalized proportions of borehole yields (based on representative success rates)	Dry or tech. neg.	41.5%	30.8%				49.8%			
	< 13 L/min	9.5%	7.6%				10.1%			
	13-70 L/min	34.8%	47.6%				26.6%			
	70-180 L/min	9.6%	11.2%				8.3%			
	> 180 L/min	4.6%	2.8%				5.2%			

Notes
(1) : Only unique boreholes with reliable coordinates were considered.
(2) : Dry and technically negative boreholes sometime have yield data (from bh constr.) even though they are now considered unsuccessful.
(3) : Representative success rates were estimated from local hydrogeological or water supply project reports collected under HAP.
(4) : The success rates presented here may not be representative everyw here in the districts considered as they were mostly derived from local studies.
(5) : The report numbers refer to the HAP report metadabase created during the collection of existing reports. This metadabase can be obtained through the Ghana Water Resources Commission.

Limits
- Country
- Regions

Settlements
- Region capitals
- District capitals

Hydrography
- Lakes
- Rivers

Potential borehole success rate
- < 20 %
- 20 - 40 %
- 40 - 60 %
- 60 - 80 %
- > 80 %

N.B.: 1) As there is an obvious bias in favor of successful boreholes in the databases consolidated under the HAP, representative success rates were estimated from collected local hydrogeological or water supply reports.
2) The success rates presented here may however not be representative everywhere in the districts considered as they were derived from local studies.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Potential borehole success rate

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International; INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_bhsuccess.mxd

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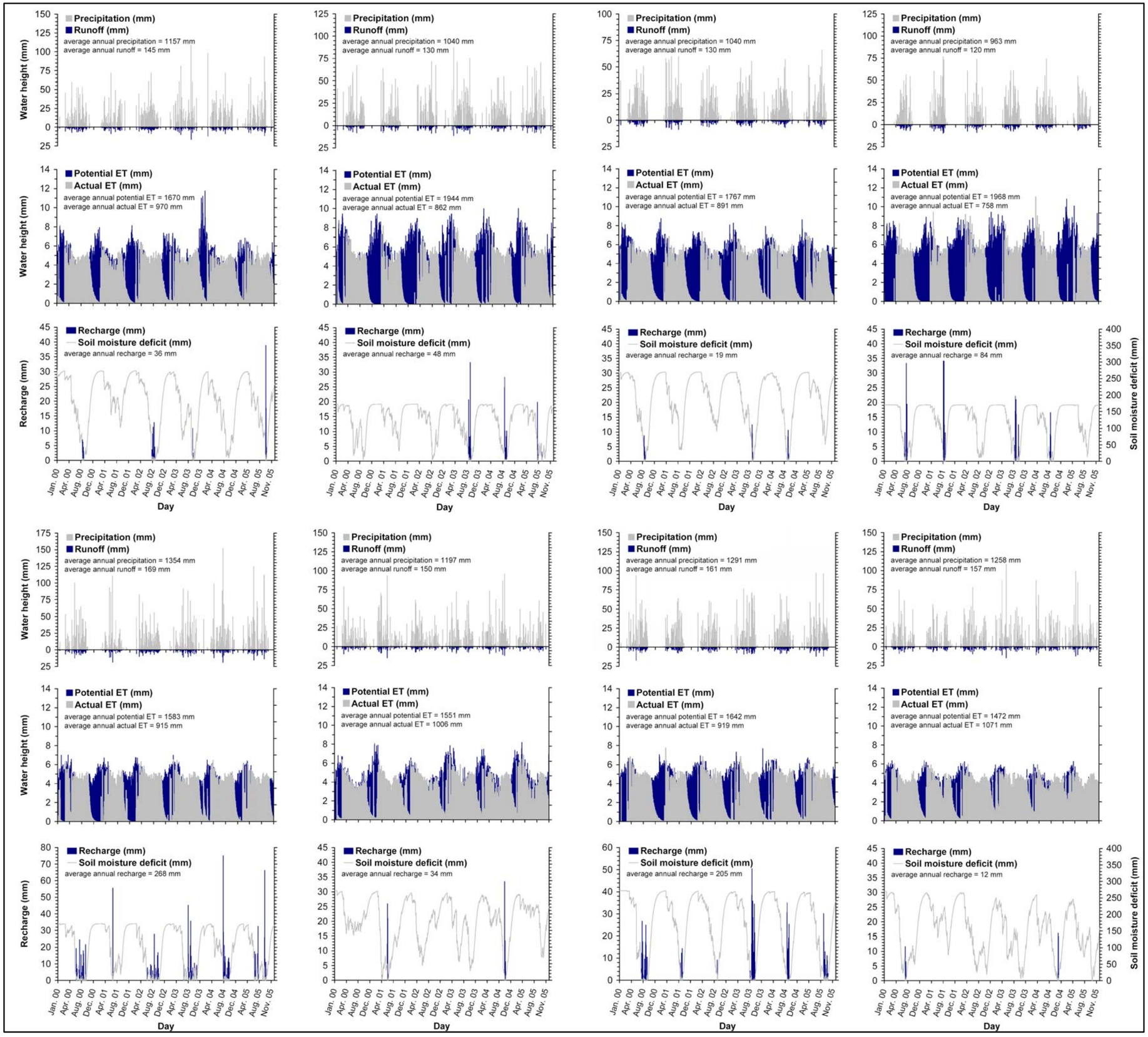
Groundwater recharge



Average annual values for the 2000-2005 period

Station	pET	P	Q	aET	R	
	(mm)	(mm)	(mm)	(mm)	(mm)	(%)
Navrongo	1968	963	120	758	84	8.8
Wa	1767	1040	130	891	19	1.8
Tamale	1944	1040	130	862	48	4.6
Yendi	1642	1291	161	919	205	15.9
Bole	1670	1157	145	970	36	3.1
Kete-Krachi	1582	1353	169	915	268	19.8
Sunyani	1551	1197	150	1006	34	2.8
Wenchi	1472	1258	157	1071	12	1

Note: pET: potential evapotranspiration; P: precipitation; Q: runoff; aET: actual evapotranspiration; R: estimated recharge

Data source: Climate data obtained from the Ghana Meteorological Services Department and from GLOWA-Volta project.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Soil moisture balance profiles

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client

Water Resources Commission

Consultant

SNC·LAVALIN International

INRS Université d'avant-garde

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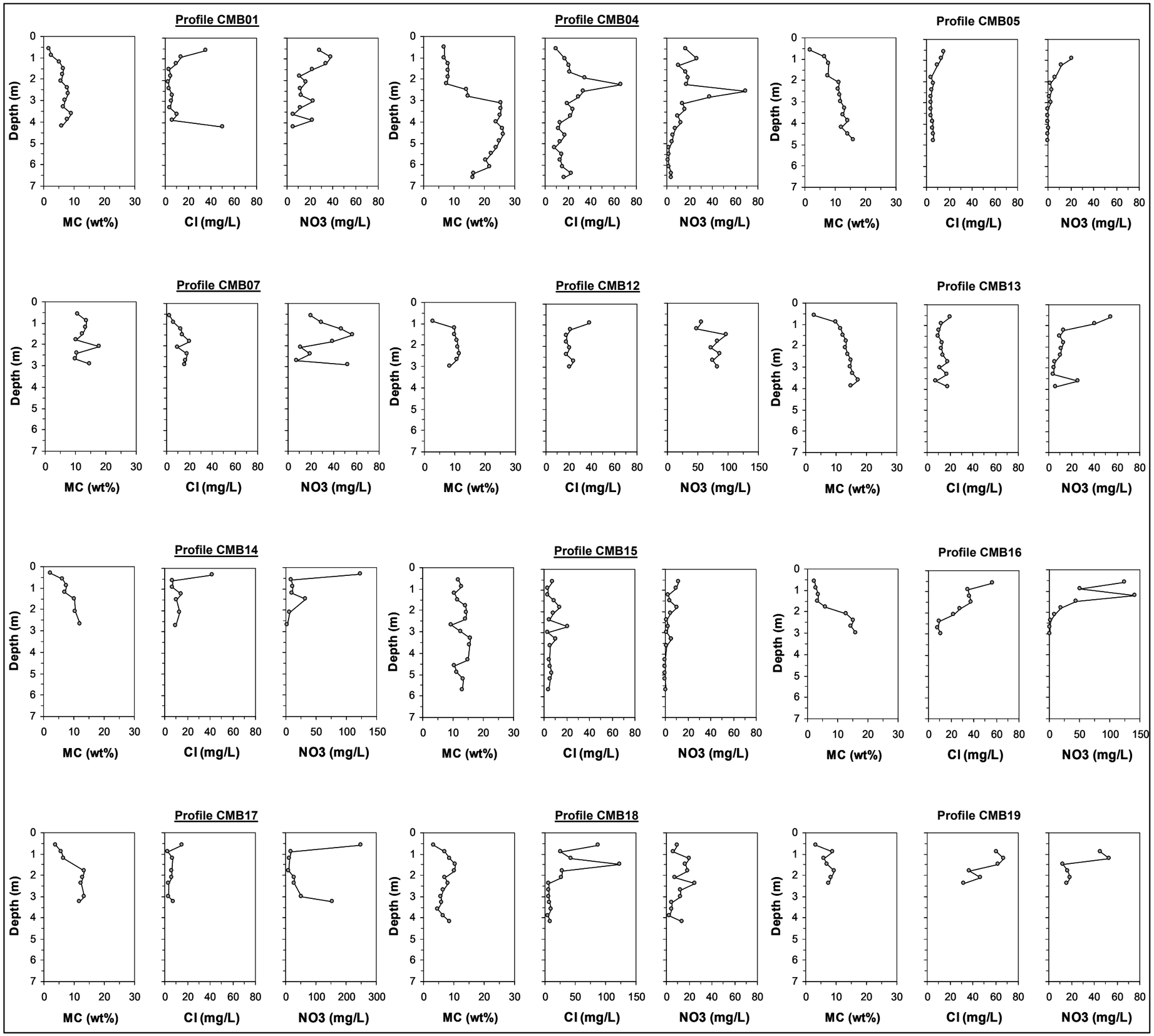

Average values for selected unsaturated zone profiles

Profile ID	D	P	Cl_P	Cl_S	R	
	(m)	(mm)	(mg/L)	(mg/L)	(mm)	(%)
CMB01	4.2	1052	0.31	9.9	33	3.1
CMB04	6.6	1034	0.36	16.6	23	2.2
CMB05	4.8	1002	0.36	5.4	68	6.8
CMB07	2.9	1184	0.43	14.2	35	3
CMB12	3	980	0.55	20.4	26	2.7
CMB13	3.9	979	0.55	13.3	40	4.1
CMB14	2.7	922	0.55	11.1	46	4.9
CMB15	5.7	938	0.55	7.5	69	7.3
CMB16	3	974	0.55	13	41	4.2
CMB17	3.3	1016	0.43	5.5	80	7.8
CMB18	4.2	1016	0.43	12.2	36	3.5
CMB19	2.7	1052	0.43	38.7	12	1.1

Note: MC: moisture content; D: profile depth; P: precipitation; CL_P: w eighted average chloride concentration in rain; CL_S: average porew ater chloride concentration; R: estimated recharge

Data source: Climate data obtained from the Ghana Meteorological Services Department and chloride data obtained from HAP.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Chloride mass balance unsaturated zone profiles

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client

Water Resources Commission

Consultant

SNC·LAVALIN International

INRS Université d'avant-garde

Scale		File name
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01	August 2011	Preliminary	M.-A. Carrier	-

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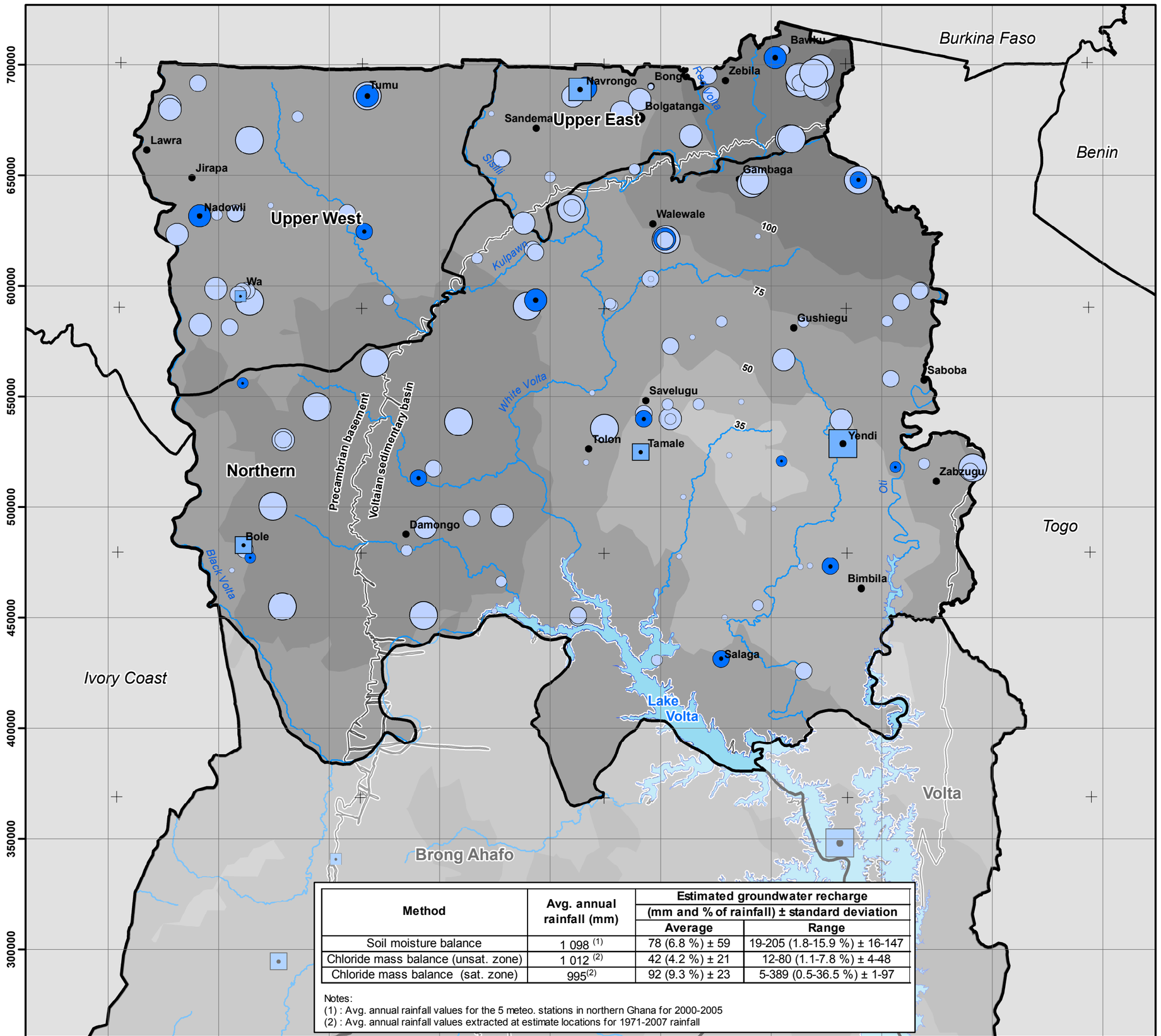

Method	Avg. annual rainfall (mm)	Estimated groundwater recharge (mm and % of rainfall) ± standard deviation	
		Average	Range
Soil moisture balance	1 098 (1)	78 (6.8 %) ± 59	19-205 (1.8-15.9 %) ± 16-147
Chloride mass balance (unsat. zone)	1 012 (2)	42 (4.2 %) ± 21	12-80 (1.1-7.8 %) ± 4-48
Chloride mass balance (sat. zone)	995(2)	92 (9.3 %) ± 23	5-389 (0.5-36.5 %) ± 1-97

Notes:
(1) : Avg. annual rainfall values for the 5 meteo. stations in northern Ghana for 2000-2005
(2) : Avg. annual rainfall values extracted at estimate locations for 1971-2007 rainfall

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Estimated recharge

Soil moiture balance recharge estimate (meteo. station)	Chloride mass balance recharge estimates: Unsaturated zone (soil profile location)	Chloride mass balance recharge estimates: Saturated zone (well location)
< 10 mm/y	< 10 mm/y	< 10 mm/y
10 - 25 mm/y	10 - 25 mm/y	10 - 25 mm/y
25 - 50 mm/y	25 - 50 mm/y	25 - 50 mm/y
50 - 100 mm/y	50 - 100 mm/y	50 - 100 mm/y
> 100 mm/y	> 100 mm/y	> 100 mm/y

Interpolated recharge

- < 35 mm/y
- 35 - 50 mm/y
- 50 - 75 mm/y
- 75 - 100 mm/y
- 100 - 150 mm/y
- > 150 mm/y

N.B.: 1) This map is intended to provide an overview of regional trends in groundwater recharge; it is thus not accurate at local scale. 2) Groundwater recharge was interpolated by ordinary kriging using estimates derived from the implementation of the chloride mass balance and the soil moisture balance methods.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Distribution of estimated recharge (Chloride Mass Balance & Soil Moisture Balance)

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_recharge.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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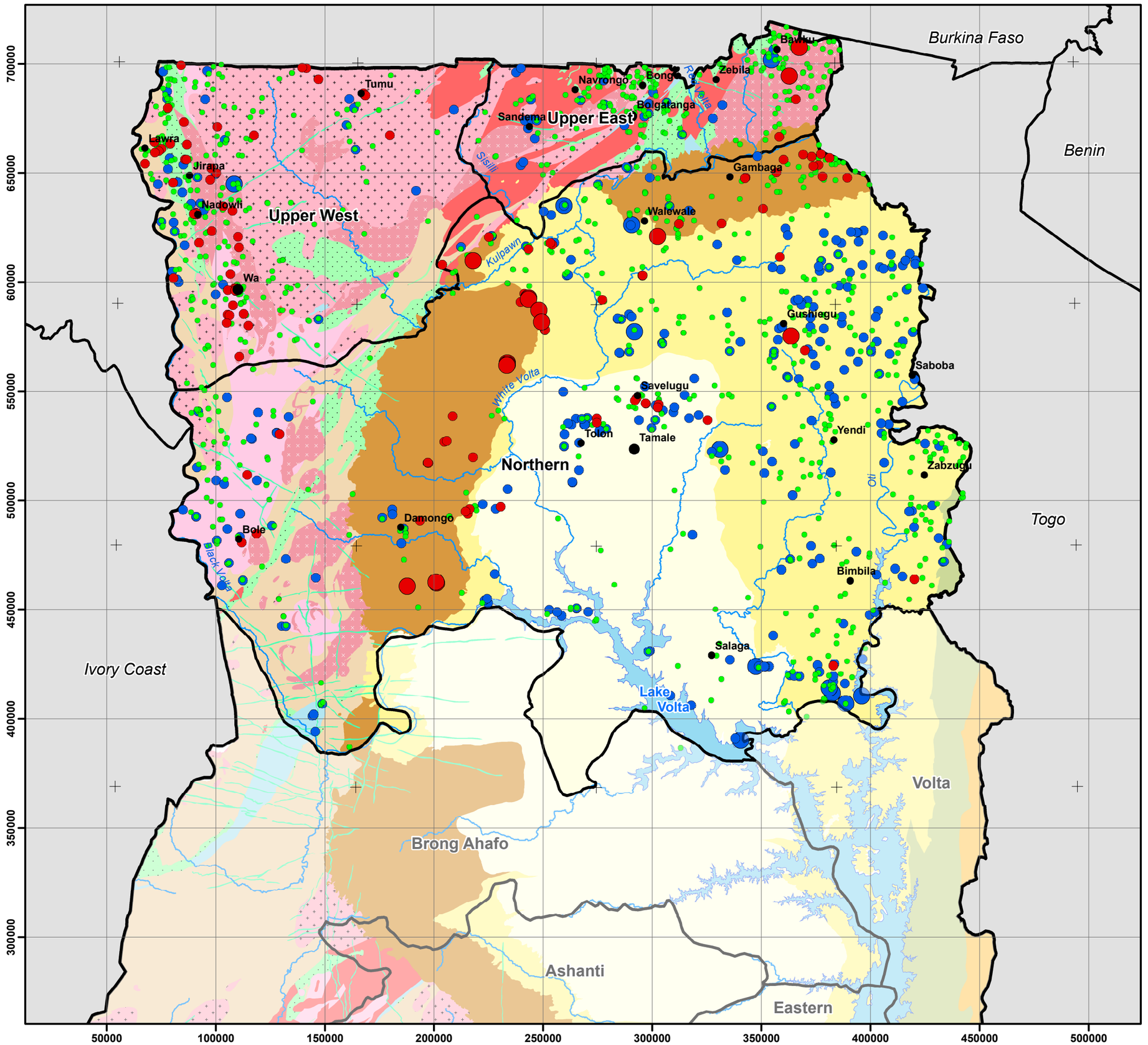
Groundwater quality



Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology (simplified)

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

pH

- 4.00 - 5.25
- 5.25 - 6.50
- 6.50 - 8.00
- 8.00 - 9.25
- 9.25 - 12.00

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - pH

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_ph.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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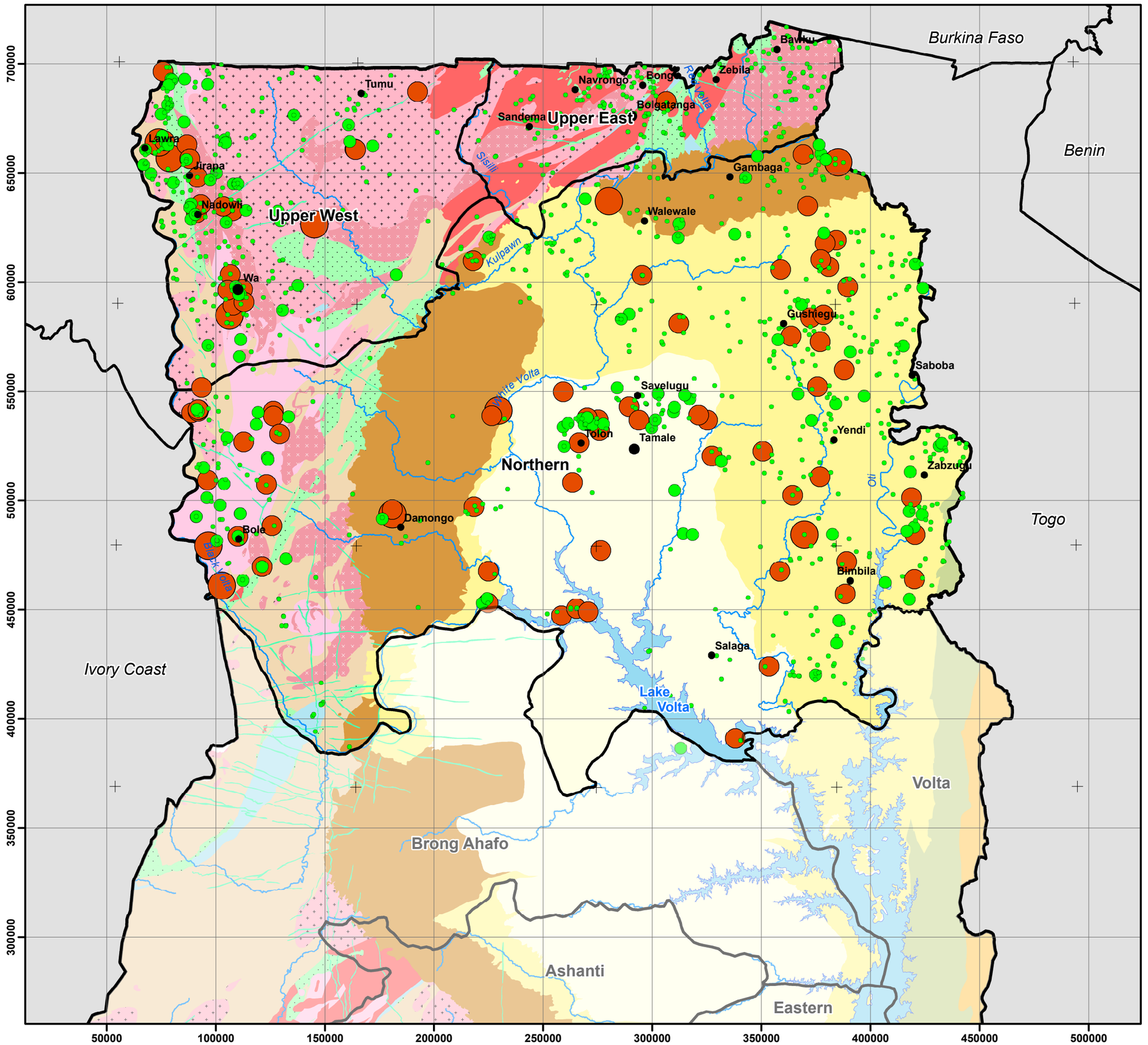

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology (simplified)

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Iron

- 0.0 - 0.15 mg/L
- 0.15 - 0.3 mg/L
- 0.3 - 2.0 mg/L
- > 2.0 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Iron

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_fe.mxd

No.	Date	Description	Drawn	Reviewed
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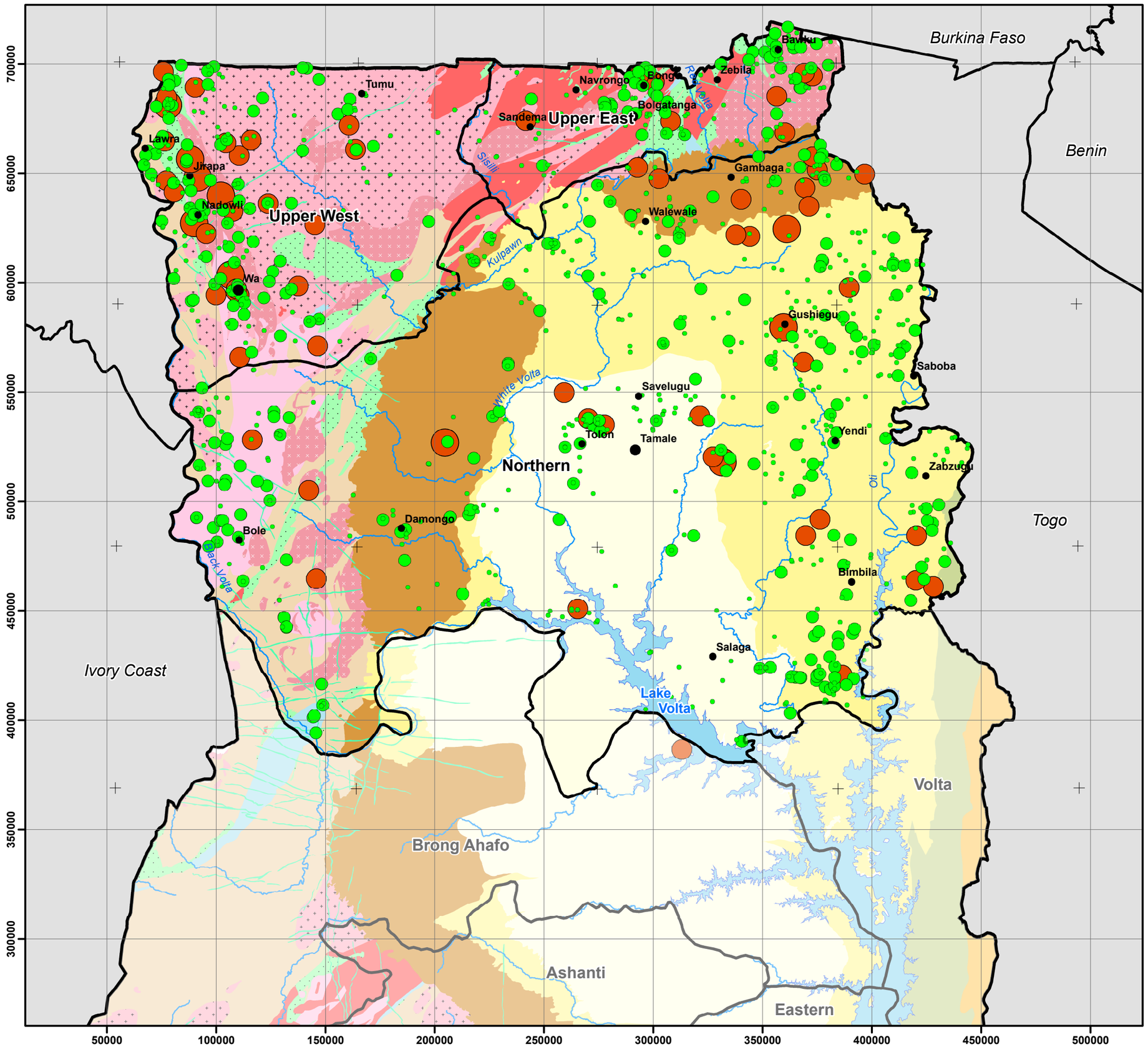

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement	Intrusive rocks
Buem Structural Unit	Mesozoic (mafic intr.)
Togo Structural Unit	Eburnean Plutonic Suite
Tarkwaian Group	Tamnean Plutonic Suite
Birimian Supergroup	Voltaian sedimentary basin
Volc. Sed. Group	Obosum Group
Volc. Plutonic Group	Oti-Pendjari Group
Synvolc. intrusives	Kwahu-Morago Group
Metamorph. Protoliths	

Manganese

- 0.0 - 0.1 mg/L
- 0.1 - 0.4 mg/L
- 0.4 - 1.0 mg/L
- > 1.0 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Manganese

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_mn.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
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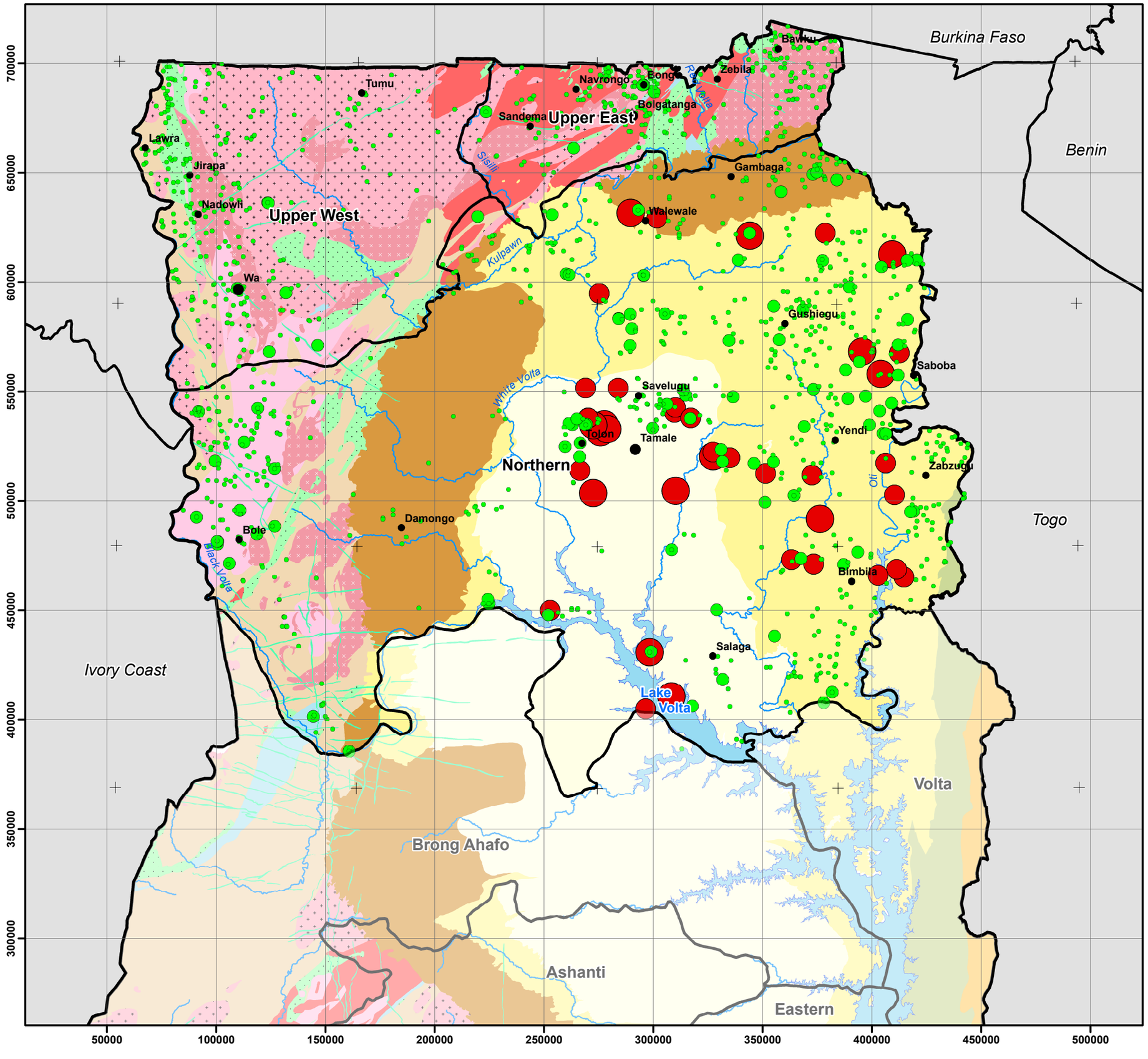

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Chloride

- 0.0 - 50 mg/L
- 50 - 250 mg/L
- 250 - 1000 mg/L
- > 1000 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Chloride

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International; INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_cl.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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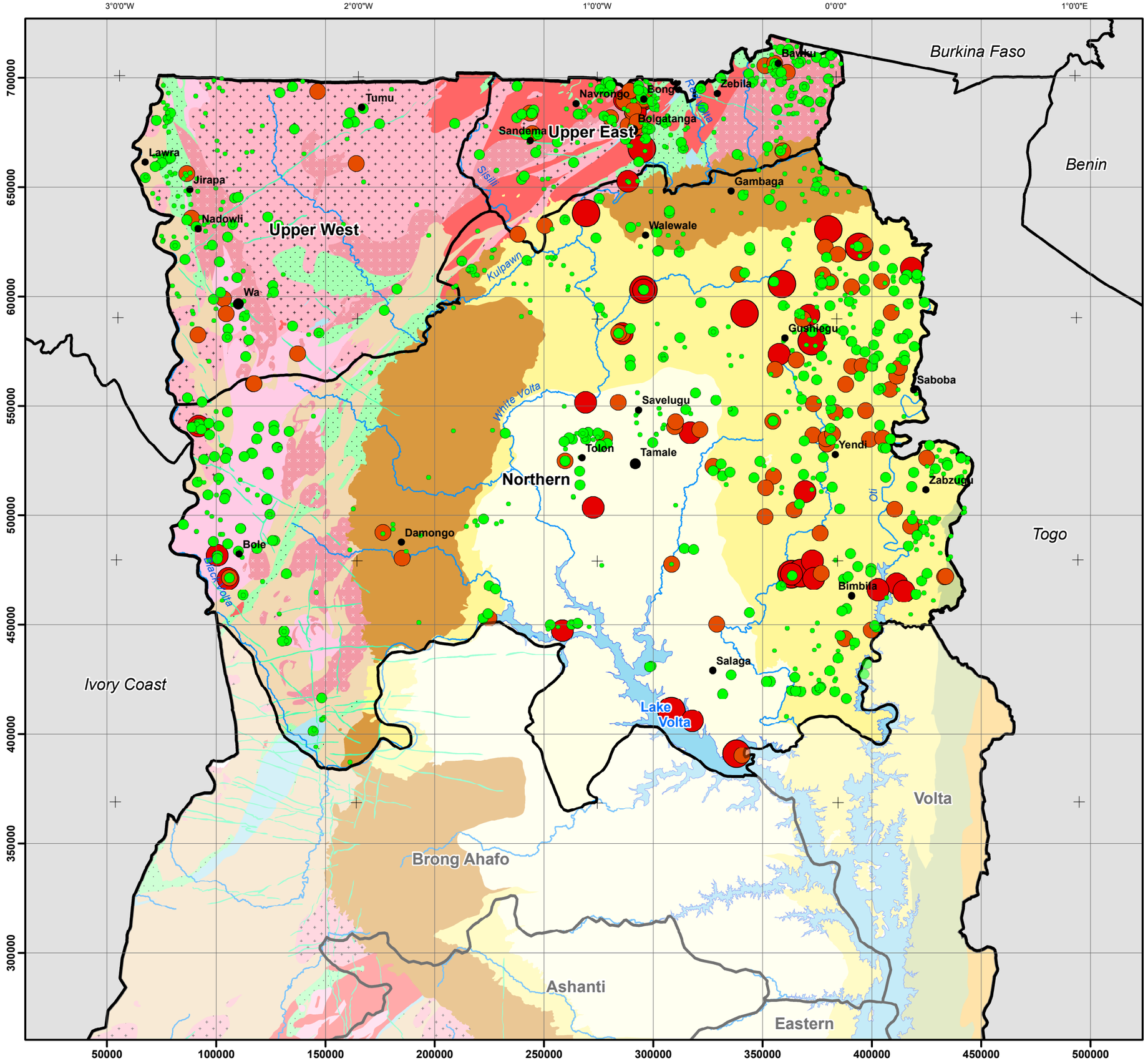

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Fluoride

- 0 - 0.5 mg/L
- 0.5 - 1.5 mg/L
- 1.5 - 3 mg/L
- 3 - 5 mg/L
- > 5 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Fluoride

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_f.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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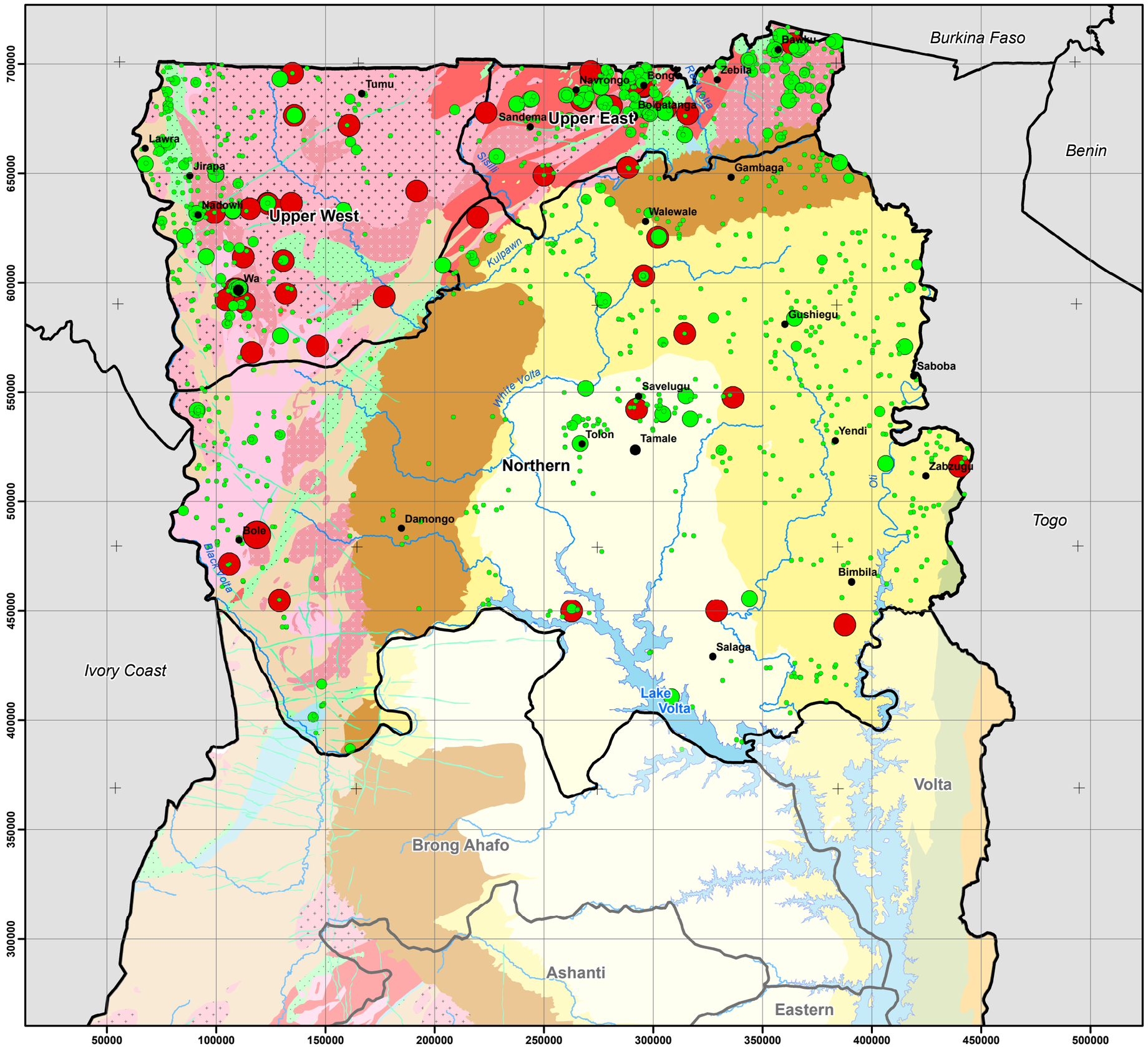

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Nitrate

- 0 - 2.5 mg/L
- 2.5 - 5 mg/L
- 5 - 10 mg/L
- 10 - 50 mg/L
- > 50 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.

Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Nitrate

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_no3.mxd

No.	Date	Description	Drawn	Reviewed
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01	August 2011	Preliminary	M.-A. Carrier	-

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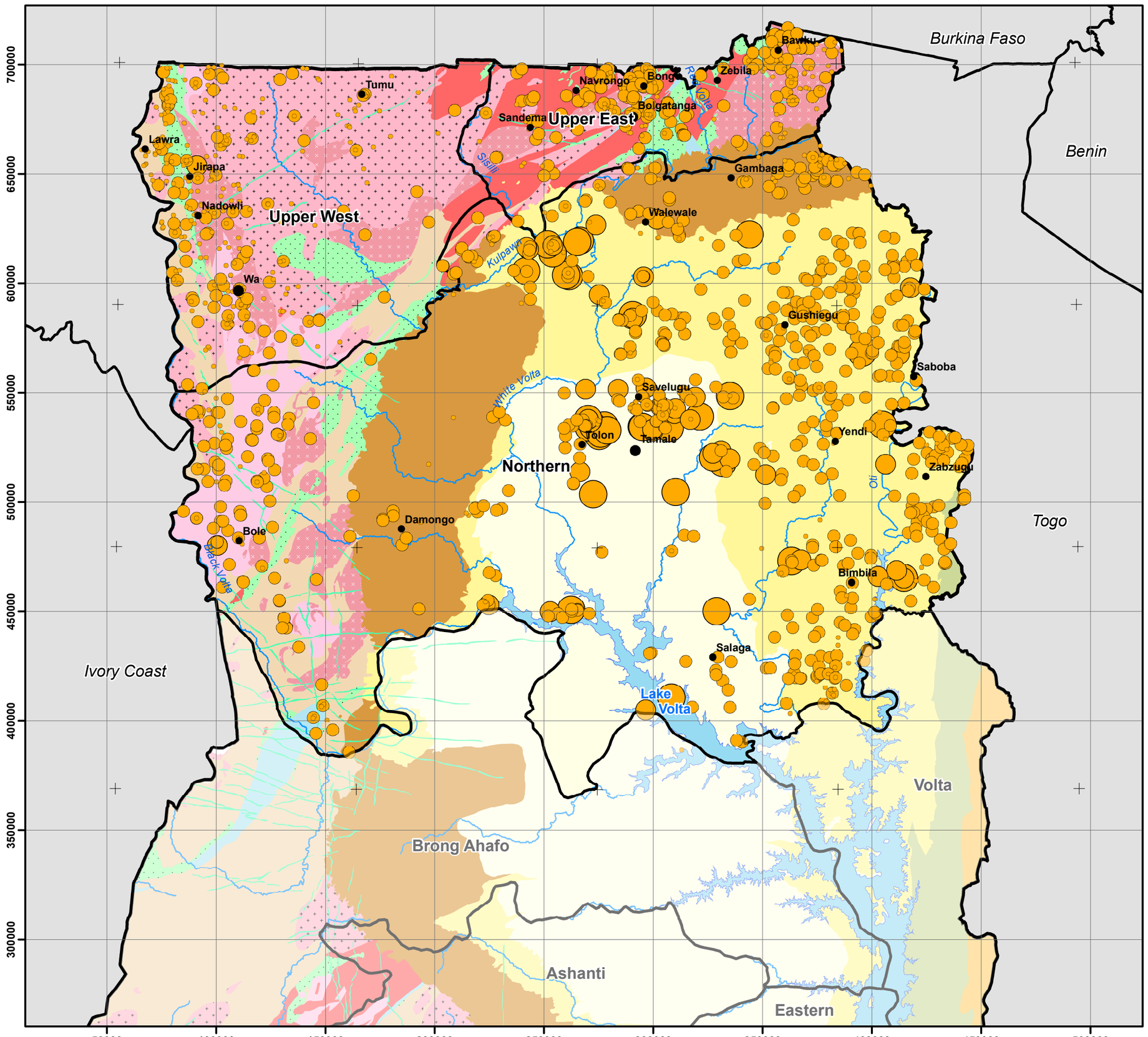

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement
- Buem Structural Unit
- Togo Structural Unit
- Tarkwaian Group
- *Birimian Supergroup*
- Volc. Sed. Group
- Volc. Plutonic Group
- Synvolc. intrusives
- Metamorph. Protoliths

Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Conductivity

- 0 - 300 µS/cm
- 300 - 1400 µS/cm
- 1400 - 3000 µS/cm
- > 3000 µS/cm

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Conductivity

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_cond.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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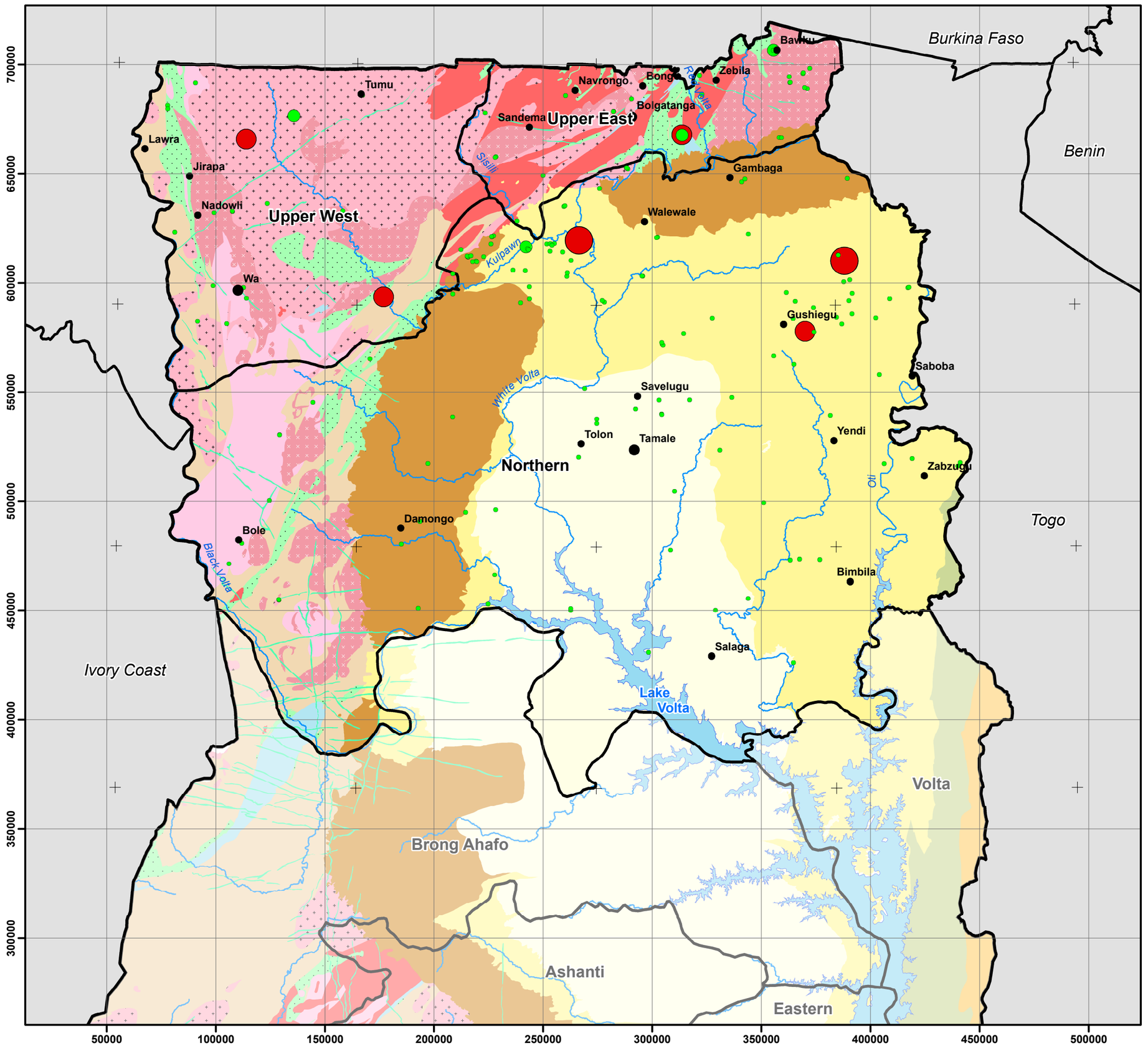

Limits

- Country
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- District capitals

Hydrography

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Geology

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Intrusive rocks
- Mesozoic (mafic intr.)
- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Arsenic

- 0.000 - 0.005 mg/L
- 0.005 - 0.010 mg/L
- 0.010 - 0.025 mg/L
- > 0.025 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Arsenic

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_as.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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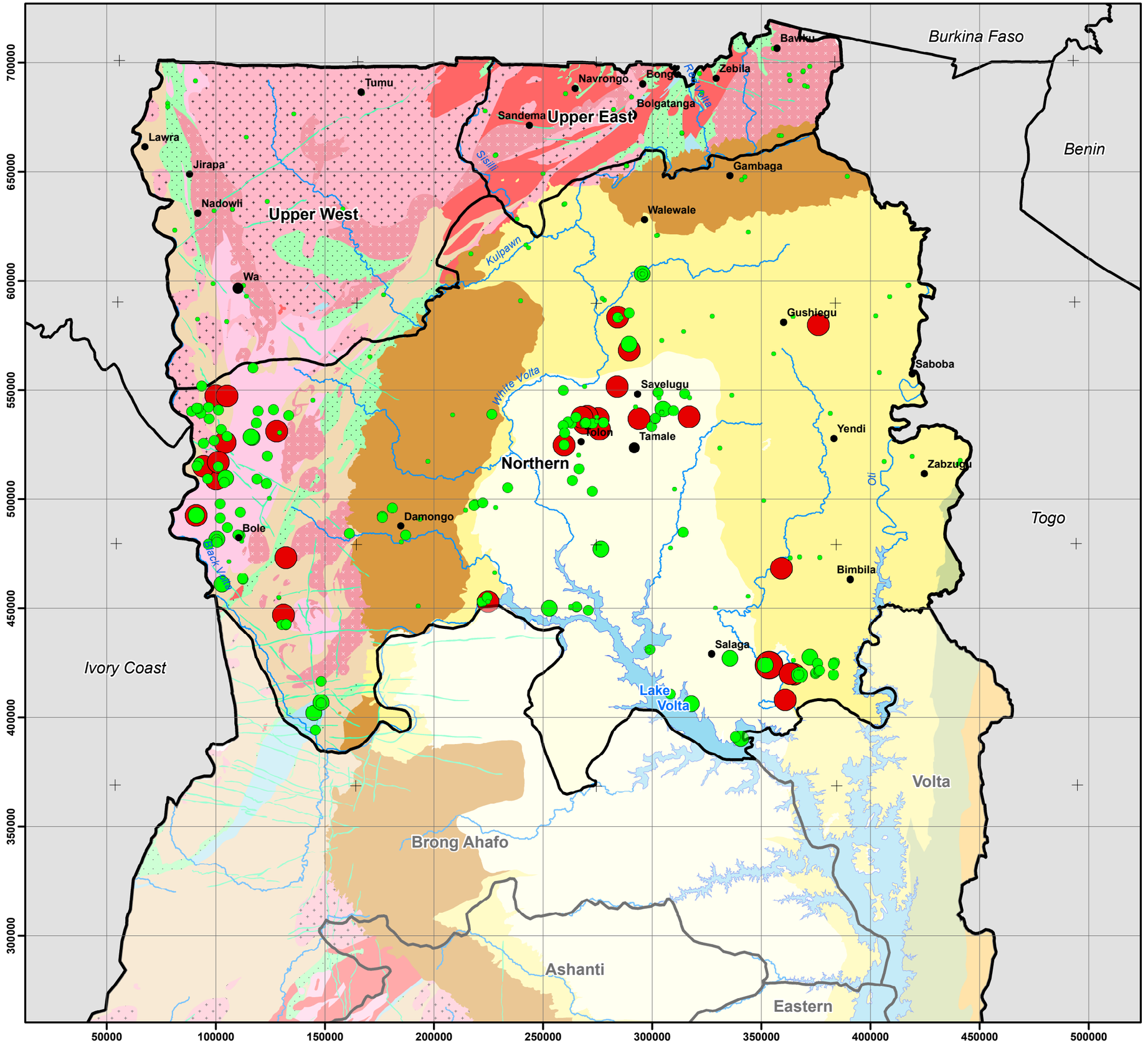

Limits

- Country
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Settlements

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Hydrography

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- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Lead

- < 0.001 mg/L
- 0.001 - 0.005 mg/L
- 0.005 - 0.01 mg/L
- 0.01 - 0.05 mg/L
- > 0.05 mg/L

Data source: Geology from Ghana Geological Survey (revised map from 2009) and all base map layers from SWERA.
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater quality - Lead

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International, INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

SLI 604138

File name: atl_gw_pb.mxd

No.	Date	Description	Drawn	Reviewed
02	November 2011	Final	M.-A. Carrier	R. Lefebvre
01	August 2011	Preliminary	M.-A. Carrier	-

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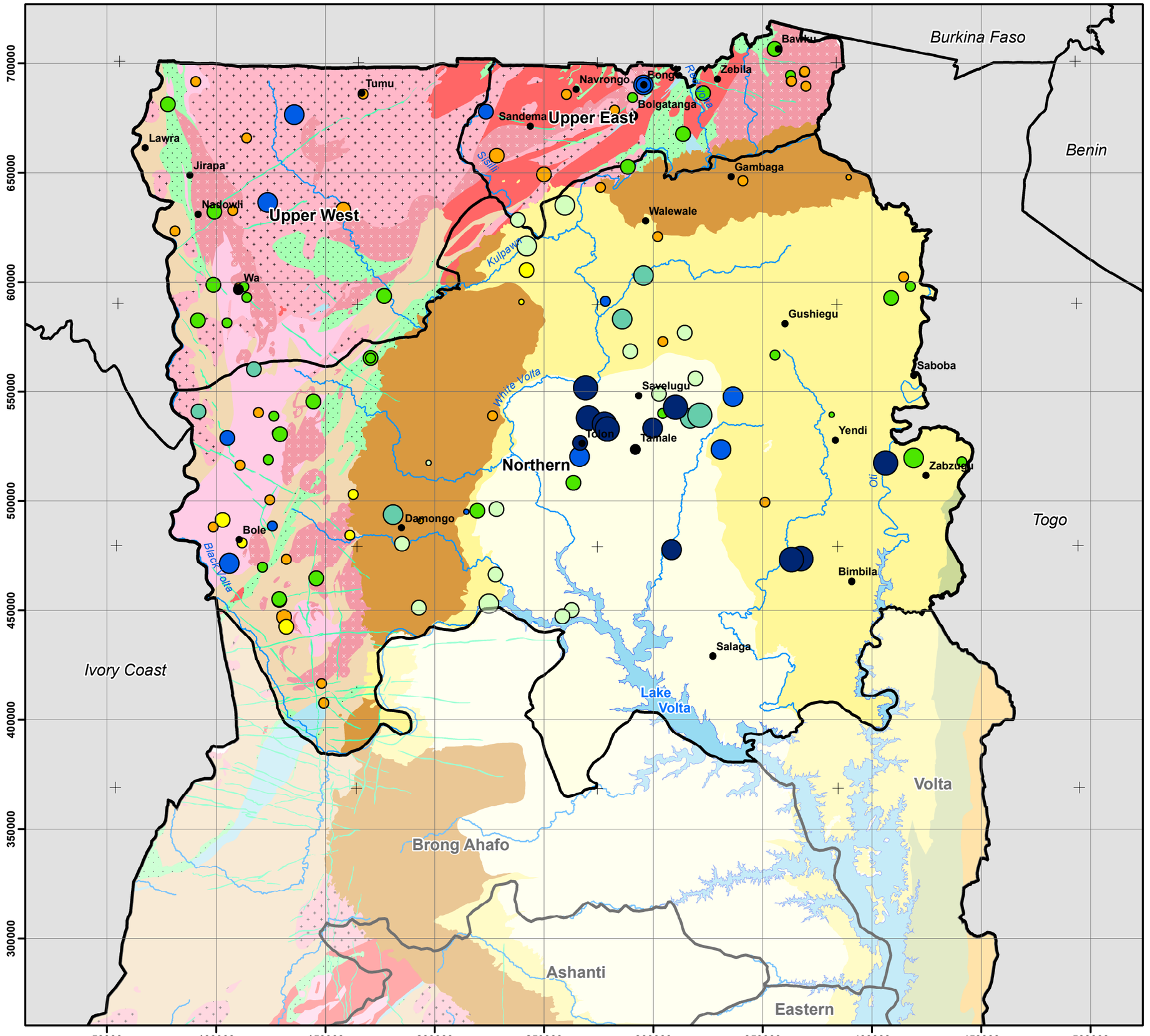

Limits

- Country
- Regions

Settlements

- Region capitals
- District capitals

Hydrography

- Lakes
- Rivers

Geology

Precambrian basement
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Intrusive rocks
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- Eburnean Plutonic Suite
- Tamnean Plutonic Suite

Voltaian sedimentary basin
- Obosum Group
- Oti-Pendjari Group
- Kwahu-Morago Group

Groundwater geochemical groups

- Ca-Mg-HCO_3
- Ca-Mg-Na-HCO_3
- Na-Ca-Mg-HCO_3
- Na-HCO_3
- Na-Ca-SO4-Cl-HCO_3
- Ca-Na-HCO_3-Cl
- Na-Cl

Total Dissolved Solids
- < 50 mg/L
- 50 - 200 mg/L
- 200 - 500 mg/L
- 500 -1000 mg/L
- > 1000 mg/L

Data source: Geology from Ghana Geol. Survey (2009 revised map).
Note: Produced with financial help from the Canadian International Development Agency (CIDA) (project no.: 7038883)

Title

Groundwater geochemical groups

Project

Hydrogeological Assessment of the Northern Regions of Ghana

Project Director	Map edited by	Verified by
Daniel Malenfant	**M.-A. Carrier**	**R. Lefebvre**

Client: **Water Resources Commission**

Consultant: SNC-LAVALIN International; INRS Université d'avant-garde

Scale: 0 10 20 40 60 km

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File name: atl_gw_cond.mxd

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02	November 2011	Final	M.-A. Carrier	R. Lefebvre
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