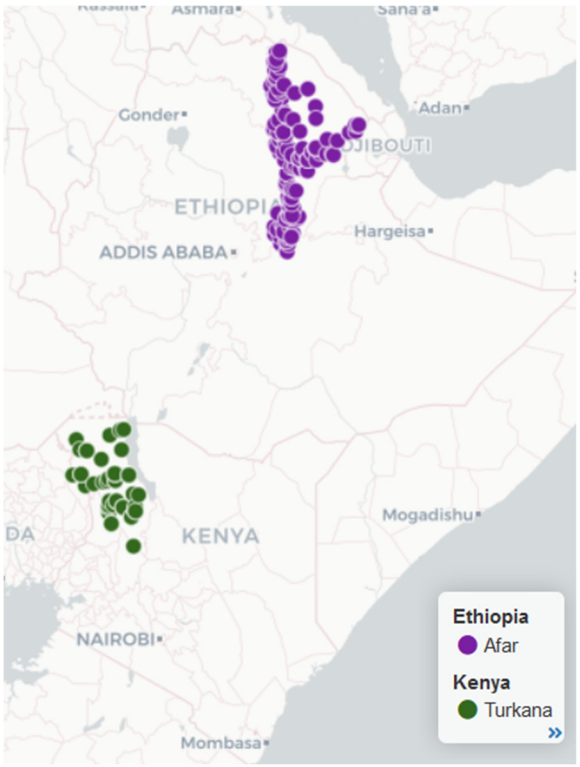
SUPPLEMENTAL MATERIALS

ASCE *Journal of Environmental Engineering*

Turn up the Dial: System Dynamics Modeling of Resource Allocations toward Rural Water Supply Maintenance in East Africa

Pranav Chintalapati, Anna Libey, Styvers Kathuni, Bernard Amadei, and Evan Thomas

DOI: 10.1061/(ASCE)EE.1943-7870.0001982



	Afar Region, Ethiopia	**Turkana County, Kenya**
Population	1,812,000 (2017)	926,976 (2019)
Area	72,053 km^2	68,233 km^2
Mean Annual Rainfall	188 mm	186 mm
# of Motorized Boreholes	300	400
Rural Basic Water Access (JMP)	34.8% (Ethiopia, 2020)	51.8% (Kenya, 2020)
Rural Safe Water Access (JMP)	5.2% (Ethiopia, 2020)	0% (Kenya, 2020)

Fig. S1. Borehole locations with sensors and characteristics of the case study regions of Turkana County, Kenya, and Afar Region, Ethiopia. [Data from Central Statistical Agency 2013; Kenya National Bureau of Statistics 2019; Climate-Data.org 2019; WHO and UNICEF 2020; map generated using mWater (mwater.co).]

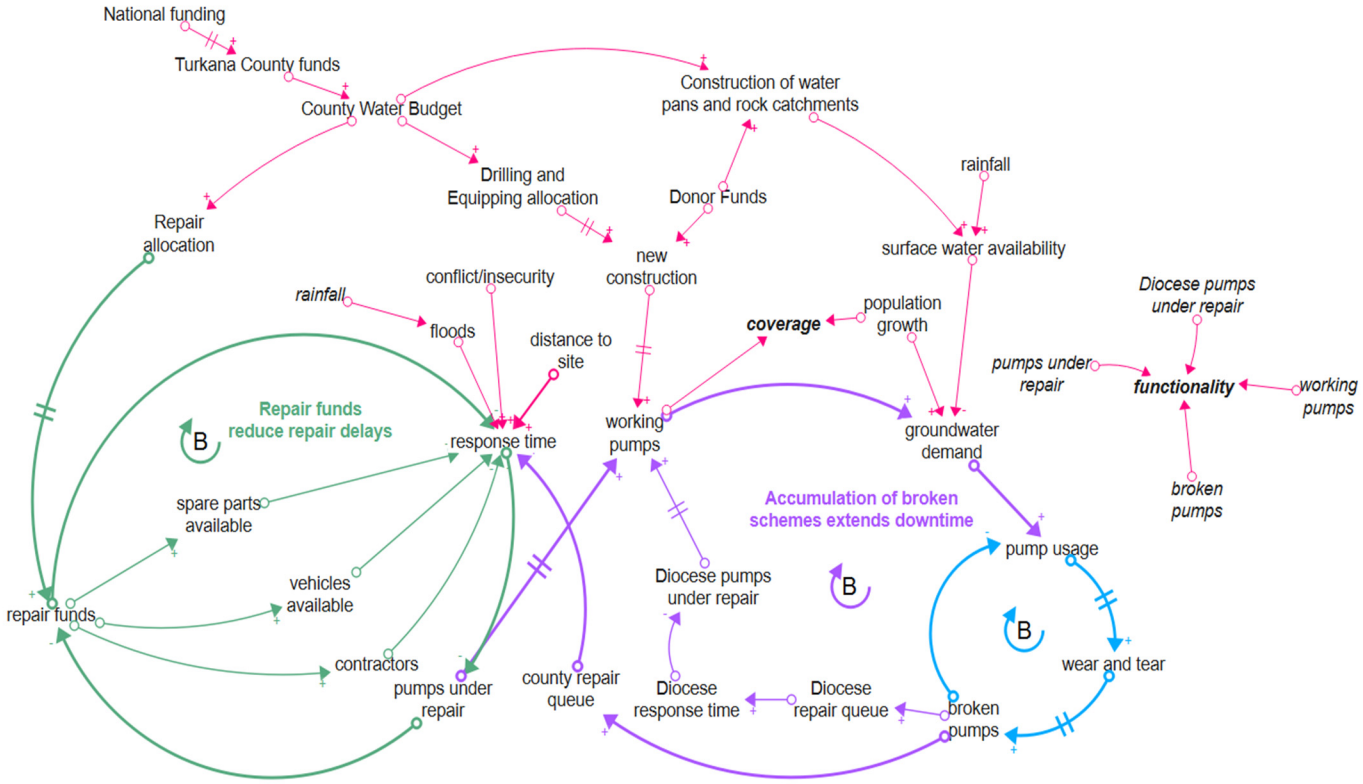


Fig. S2. The causal loop diagram of the Turkana rural water system shows balancing feedback loops of pump usage leading to wear and tear and eventual breakdowns, reducing overall use (blue). The accumulation of broken pumps leads to extended response times and delayed repairs (purple). Repair and maintenance funds increase the availability of resources and reduce repair delays, increasing the number of working pumps (green). Output variables, in bold, are functionality and coverage.

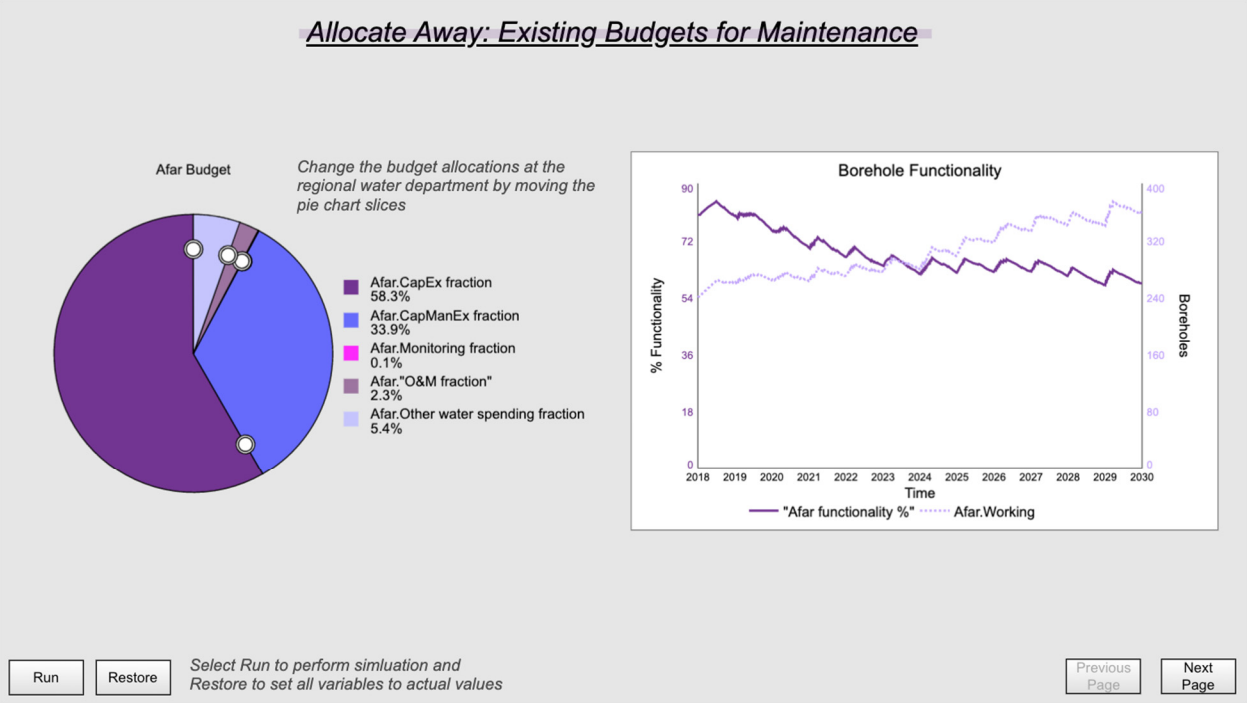


Fig. S3. Screenshot of page 1 out of 4 of the model interface for adjusting resources to support water service delivery and motorized borehole government-led maintenance. The published model interface can be found on the ISEE Systems Exchange at: [https://exchange.iseesystems.com/public/alibey/kenya-ethiopia-maintenance/index.html#page1], where readers may adjust budget allocations themselves and see the resulting impacts on simulated borehole functionality in the regions. The borehole maintenance interface is a dissemination tool for optimization and comparison of the current funding levels for maintenance in the regions with potential scenarios for "turning up the dial" on resources for improved functionality, and to see what additional increases in funding are needed to reverse current downward trends.

Table S1. Model Variables

S = stock, F = flow, C = converter, * = arrayed variable

Variables	Type	Value or Equation	Units	Source if input
Afar."breaking (non rounded)"	F	breakdown_rate	Boreholes/Weeks	
Afar."Building/admin maintenance"	F	PULSE(0.9*CapManEx_Funds, 3, 52)	ETB/Weeks	
Afar."Donor funds (USD)"	C	Graphical input ranging from 0 to 10000000 USD	USD	
Afar."Donor/National Agency installation rate"	C	"Donor_funds_(USD)"*earmarked_for_new_construction/BH_unit_cost	units/year	

Afar."installing/fixing sensors"	F	IF(Monitoring_Funds>(cost_per_sensor*(1+inflation)^(TIME/52)) AND Sensors<total_boreholes) THEN(target_sensor_install_rate) ELSE 0	sensors/Weeks	
Afar."Maintenance tools, phones"	C	100000	ETB	AWIEB Budget
Afar."removing/ breaking sensors"	F	ROUND(Sensors/sensor_lifetime)	sensors/Weeks	
Afar.access	C	Working*1600/rural_population	persons	
Afar.Admin allocation	C	PULSE(Other_water_spending_fraction*(donor_funding+Water_Bureau_Allocation), 1, 52)	ETB/Weeks	
Afar.Airtime costs	C	21600	ETB	AWIEB Budget
Afar.all broken	C	SUM(Broken[*])	Boreholes	
Afar.Asset inventory updating mWater	C	100000	ETB	AWIEB Budget
Afar.Available Heavy Equipment	S	heavy_vehicle_purchasing + heavy_vehicles_returning - heavy_vehicles_deploying - expiring	vehicles	
Afar.Available light vehicles	S	light_vehicle_purchasing + light_vehicles_returning - light_vehicles_deploying - expiring_1	vehicles	
Afar.available spare parts	C	minor_parts_in_stock+major_parts_in_stock	parts	
Afar.avg driving distance per day	C*	80 km/hr * 6 hours of driving if Breakdown_type = Minor, 50 kn/hr * 6 hours of driving if Breakdown_type = Major	Kilometers/days	
Afar.avg production	C	MAX(0, NORMAL(7.323458, 5))	L/s	Afar asset inventory
Afar.BH unit cost	C	3730000	ETB	AWIEB Budget
Afar.breakdown rate	C	SAFEDIV(breakdowns, TIME)	Boreholes/Weeks	
Afar.breakdown threshold	C	Set using model calibration	Hours	
Afar.breakdowns	C	Hours_pumped/breakdown_threshold	Boreholes	
Afar.breakdowns verified	C	MAX(10, Sensors)	Boreholes/Days	
Afar.breaking	F*	ROUND(breakdown_rate*(1-major_breakdown_probability)) if Breakdown_type = Major, ROUND(breakdown_rate*minor_breakdown_probability) if Breakdown_type = Minor	Boreholes/Weeks	
Afar.Broken	S*	breaking - repairing	Boreholes	
Afar.Capacity building to woredas	C	70000	ETB	AWIEB Budget
Afar.CapEx allocation	F	PULSE(CapEx_fraction*(Water_Bureau_Allocation+donor_funding), 1, 52)	ETB/Weeks	

Afar.CapEx fraction	C	0.195	ETB	AWIEB Budget
Afar.capital equipment spending	F	(Cost_per_heavy_vehicle*vehicle_purchasing +light_vehicle_purchasing*cost_per_light_vehicle)*(1+inflation)^(TIME/52)	ETB/Weeks	
Afar.CapManEx allocation	F	PULSE(CapManEx_fraction*(Water_Bureau_Allocation+donor_funding), 1, 52)	ETB/Weeks	
Afar.CapManEx fraction	C	0.375	ETB	AWIEB Budget
Afar.CapManEx Funds	S	CapManEx_allocation - Building/admin maintenance - spare_parts_spending - capital_equipment_spending	ETB	
Afar.construction spending	F	(new_construction*BH_unit_cost)*(1+inflation)^(TIME/52)	ETB/Weeks	
Afar.Cost per heavy vehicle	C	1702000	ETB	Expert Consultation
Afar.cost per light vehicle	C	1702000	ETB	Expert Consultation
Afar.cost per sensor	C	35000	ETB	Expert Consultation
Afar.coverage	C	total_boreholes*persons_per_bh/rural_population	persons	
Afar.Deployed technicians	S	sending_to_the_field - sending_back	persons	
Afar.Disasters Factor	C	MONTECARLO(15)	unitless	
Afar.distance to site	C	WEIBULL(1.22723, 269.56621, 1, 5, 800)	Kilometers	Afar asset inventory
Afar.donor funding	F	DELAY(PULSE(donor_funds, 1, 52), 212, 0)	ETB/Weeks	
Afar.donor funds	C	"Donor_funds_(USD)"*39.55*(1-earmarked_for_new_construction)	ETB/Weeks	
Afar.Donor installing	F	PULSE(1, 1, SAFEDIV(52, "Donor/National_Agency_installation_rate"))	Boreholes/Weeks	
Afar.earmarked for new construction	C	Adjusted between 0-1 in interface (representing 0-100%)	%	
Afar.expiring	F	PULSE(1, 1, 104)	vehicles/weeks	
Afar.fuel cost per day	C*	25*8/100*avg_driving_distance_per_day[Minor] if Breakdown_type=Minor, 25*29/100*avg_driving_distance_per_day[Major] if Breakdown_type=Major	ETB	
Afar.functionality	C	Working_total_boreholes	Boreholes	
Afar.gov perdium	C	1700	ETB/day	Expert Consultation
Afar.growth rate	C	0.026	rate	Central Statistical Agency of Ethiopia

Afar.GSM sensors bill	C	42000	ETB	AWIEB Budget
Afar.Heavy Equipment in the field	S	heavy_vehicles_deploying - heavy_vehicles_returning	vehicles	
Afar.heavy vehicle purchasing	F	IF (CapManEx_Funds>Cost_per_heavy_vehicle*(1+inflation)^(TIME/52)) THEN (IF ((Available_Heavy_Equipment+Heavy_Equipment_in_the_field)<total_technicians/5) THEN PULSE(target_vehicle_purchase_rate, 1, 52) ELSE 0) ELSE 0	vehicles/week	
Afar.heavy vehicle spending	F	(fuel_cost_per_day[Major]*major_repair_days)*(1+inflation)^(TIME/52)	ETB/Weeks	
Afar.heavy vehicles deploying	F	IF major_breakdown_probability = 1 AND major_parts_in_stock > parts_per_repair[Major]*Available_Heavy_Equipment AND minor_parts_in_stock > parts_per_repair[Minor]*Available_Heavy_Equipment AND sending_to_the_field >=2 THEN ROUND(Available_Heavy_Equipment/(major_response_time/7)) ELSE IF minor_parts_in_stock > parts_per_repair[Major]*Available_Heavy_Equipment THEN ROUND(Available_Heavy_Equipment/(major_response_time/7)) ELSE 0	vehicles/week	
Afar.heavy vehicles returning	F	ROUND(Heavy_Equipment_in_the_field/(major_repair_days/7))	vehicles/week	
Afar.hiring cost	C	minor_repair_days*vehicle_rental_cost*(1+inflation)^(TIME/52)	ETB	
Afar.hiring technicians	F	ROUND(PULSE(target_technician_hiring, 1, 52))	persons/Weeks	
Afar.Hours pumped	S	pumping	Hours	
Afar.inflation	C	0.04	rate	World Bank Databank
Afar.Insecurity Factor	C	MONTECARLO(10)	unitless	
Afar.Installation funds	S	CapEx_allocation - construction_spending	ETB	

Afar.light vehicle purchasing	F	IF (CapManEx_Funds>cost_per_light_vehicle*(1+inflation)^(TIME/52)) AND (Available_light_vehicles+Light_vehicles_in_the_field)<total_technicians/2 THEN PULSE(target_vehicle_purchase_rate, 1, 52) ELSE 0	vehicles/week	
Afar.light vehicle renting time	C	IF Available_light_vehicles = 0 THEN 7 ELSE 0	Days	
Afar.light vehicle spending	F	(hiring_cost*renting_vehicle+fuel_cost_per_day[Minor]*minor_repair_days)*(1+inflation)^(TIME/52)	ETB/Weeks	
Afar.light vehicles deploying	F	IF minor_parts_in_stock > parts_per_repair[Minor] AND Available_light_vehicles >= 1 AND sending_to_the_field >= 1 THEN ROUND(Available_light_vehicles/(minor_response_time/7)) ELSE 0	vehicles/week	
Afar.Light vehicles in the field	S	light_vehicles_deploying - light_vehicles_returning	vehicles	
Afar.light vehicles returning	F	ROUND(Light_vehicles_in_the_field/(minor_repair_days/7))	vehicles/week	
Afar.major breakdown fraction	C	20	%	Expert consultation
Afar.major breakdown probability	C	MONTECARLO(major_breakdown_fraction)	unitless	
Afar.major parts arriving	F	ROUND(Major_Parts_procured/procurement_delay)	parts/weeks	
Afar.major parts cost	C	400000	ETB	Expert consultation
Afar.major parts in stock	S	major_parts_arriving - using_major_parts	parts	
Afar.Major Parts procured	S	purchasing_major_parts - major_parts_arriving	parts	
Afar.major repair days	C	2 + ROUND((distance_to_site/avg_driving_distance_per_day[Major])*2)	days	
Afar.major response time	C	time_to_identify_breakdown+response_delay	days	
Afar.max gov install rate	C	2	Boreholes/Months	Expert Consultation
Afar.minor parts arriving	F	ROUND(Minor_Parts_procured/procurement_delay)	parts/weeks	
Afar.minor parts cost	C	10000	ETB	Expert Consultation

Afar.minor parts in stock	S	minor_parts_arriving - using_minor_parts	parts	
Afar.Minor Parts procured	S	purchasing_minor_parts - minor_parts_arriving	parts	
Afar.minor repair days	C	2 + ROUND((distance_to_site/avg_driving_distance_per_day[Minor])*2)	days	
Afar.minor response time	C	time_to_identify_breakdown+1+response_delay	days	
Afar.Monitoring allocation	F	PULSE(Monitoring_fraction*(Water_Bureau_Allocation+donor_funding), 1, 52)	ETB/Weeks	
Afar.Monitoring fraction	C	0.001	ETB	AWIEB Budget
Afar.Monitoring Funds	S	monitoring_allocation - monitoring_spending	ETB	
Afar.monitoring spending	F	PULSE((("Maintenance_tools,_phones"+Asset_inventory_updating_mWater+Airtime_costs+GSM_sensors_bill+Capacity_building_to_woredas)/12)*(1+inflation)^(TIME/52), 1, 4) + Sensor_maintenance	ETB/Weeks	
Afar.MoWIE support to regions	C	2396665910	ETB	AWIEB Budget
Afar.new construction	F	MIN(ROUND(Installation_funds/(BH_unit_cost*target_BH_installs/52)), PULSE(max_gov_install_rate, 1, 4))	boreholes/weeks	
Afar.O&M allocation	F	PULSE(O&M_fraction*(donor_funding+Water_Bureau_Allocation), 1, 52)	ETB/weeks	
Afar.O&M fraction	C	0.375	ETB	AWIEB Budget
Afar.O&M Funds	S	O&M_allocation-heavy_vehicle_spending - light_vehicle_spending	ETB	
Afar.Other Depts	F	Regional_government_allocation*.9	ETB/weeks	
Afar.Other water spending fraction	C	0.054	ETB	AWIEB Budget
Afar.parts per repair	C	5 if Breakdown_Type = Major, 1 if Breakdown_Type = Minor	parts	expert consultation
Afar.per capita demand	C	13	Liters/person	expert consultation
Afar.per capita usage	C	Water_Storage/(rural_population*coverage)	Liters/person	
Afar.persons per bh	C	1600	persons	Afar asset inventory
Afar.procurement delay	C	IF CapManEx_Funds > 50000000 THEN 8 ELSE 52	weeks	expert consultation
Afar.producing	F	avg_production*360*Working*weekly_pumping_hours	L/weeks	
Afar.pumping	F	weekly_pumping_hours*Working*reliability_multiplier	Hours/weeks	
Afar.purchasing major parts	F	ROUND(PULSE(target_parts_purchase_rate[Major], 2, 52))	parts/Weeks	

Afar.purchasing minor parts	F	ROUND(PULSE(target_parts_purchase_rate[Minor], 2, 52))	parts/Weeks	
Afar.refunctioning	F	INF	Boreholes/weeks	
Afar.Region Funds	S	Regional_government_allocation - Water_bureau_allocation - Other_depts	ETB	
Afar.Regional government allocation	F	PULSE(MoWIE_support_to_regions*(1+Yearly_budget_growth)^(TIME/52), 1, 52)	ETB/Weeks	
Afar.reliability multiplier	C	Graphical exponential function where x axis is the number of Working boreholes and the y is between 1 and 2	unitless	
Afar.Rented light vehicles	S	renting_vehicle - returning_vehicle	vehicles	
Afar.renting vehicle	F	IF(O&M_Funds>hiring_cost) THEN ROUND(target_vehicle_rentals) ELSE 0	vehicles/weeks	
Afar.repair rate	C*	light_vehicles_returning if Breakdown_type = Minor, heavy_vehicles_returning of Breakdown_type = Major	boreholes/weeks	
Afar.Repaired	S	repairing - refunctioning	Boreholes	
Afar.repairing	F	repair_rate[*]	boreholes/weeks	
Afar.response delay	C	IF Insecurity_Factor+Disasters_Factor > 0 THEN 30 ELSE 0	days	
Afar.returning vehicle	F	ROUND(Rented_light_vehicles/minor_repair_days)	vehicles/week	
Afar.rural population	C	1812002*(1+(growth_rate))^(TIME/52)	persons	Central Statistical Agency of Ethiopia
Afar.salary	C	4741719	ETB	expert consultation
Afar.sending back	F	ROUND(SAFEDIV(Deployed_technicians, minor_repair_days))	persons/week	
Afar.sending to the field	F	IF(O&M_Funds>=technician_cost) THEN (MIN(techs_needed, 5)) ELSE 0	persons/week	
Afar.sensor coverage	C	Sensors/total_boreholes	%	
Afar.sensor lifetime	C	NORMAL(100, 20, 1, 4, 300)	weeks	Sensor data
Afar.Sensor maintenance	C	cost_per_sensor*"installing/fixing_sensors"	ETB	
Afar.Sensors	S	installing/fixing_sensors - removing/breaking_sensors	sensors	
Afar.spare parts spending	F	(major_parts_cost*purchasing_major_parts+minor_parts_cost*purchasing_minor_parts)*(1+inflation)^(TIME/52)	ETB/weeks	

Afar.target BH installs	C	Graphical function where target installs decreases from 24 to 0 as coverage goes from 0 to 1	Boreholes/year	
Afar.target parts purchase rate	C	100 if Breakdown_Type = Major, 50 if Breakdown_Type = Minor	parts/year	
Afar.target sensor install rate	C	"removing/_breaking_sensors"+new_construction+Donor_installing	sensors	
Afar.target technician hiring	C	IF(donor_funds*Other_water_spending_fraction > (salary*(1+inflation)^(TIME/52))) THEN 2 ELSE IF O&M_Funds > 20000000 THEN O&M_Funds/(salary*(1+inflation)^(TIME/52)) ELSE 1	persons/year	
Afar.target vehicle purchase rate	C	1	vehicles/year	
Afar.target vehicle rentals	C	MIN(ROUND(Broken[Major]), 5)	vehicles/week	
Afar.technician cost	C	gov_perdium*minor_repair_days*(1+inflation)^(TIME/52)	ETB	
Afar.technician spending	C	sending_to_the_field*technician_cost*(1+inflation)^(TIME/52) + hiring_technicians*salary*(1+inflation)^(TIME/52)	ETB/weeks	
Afar.Technicians	S	hiring_technicians + sending_back - sending_to_the_field	persons	
Afar.techs needed	C	(Broken[Minor]+Broken[Major])*2	persons	
Afar.time to identify breakdown	C	ROUND(1/breakdowns_verified + 1)	days	
Afar.total boreholes	C	Working+Repaired+Broken[Minor]+Broken[Major]	Boreholes	
Afar.total heavy vehicles	C	Available_Heavy_Equipment+Heavy_Equipment_in_the_field	vehicles	
Afar.total light vehicles	C	Available_light_vehicles+Light_vehicles_in_the_field	vehicles	
Afar.total technicians	C	Technicians+Deployed_technicians	persons	
Afar.using major parts	F	IF major_breakdown_probability = 1 THEN (parts_per_repair[Major]+parts_per_repair[Minor])*heavy_vehicles_deploying ELSE 0	parts/week	
Afar.using minor parts	F	parts_per_repair[Minor]*light_vehicles_deploying	parts/week	
Afar.vehicle rental cost	C	10000	ETB	expert consultation
Afar.Water Bureau Allocation	F	PULSE(Water_Bureau_fraction*Regional_government_allocation, 1, 52)	ETB/weeks	
Afar.Water Bureau fraction	C	0.1	ETB	AWIEB Budget

Afar.Water Bureau Funds	S	Water_bureau_allocation + donor_funding - admin_allocation - CapEx_allocation - Monitoring_allocation - CapManEx_allocation - O&M_allocation	ETB	
Afar.water demand	F	per_capita_demand*7*rural_population*coverage	L/weeks	
Afar.Water Storage	S	producing_water_demand	Liters	Afar asset inventory
Afar.weekly pumping hours	C	Imported graphical function	Hours/week	Sensor data
Afar.Working	S	Donor_installing + new_construction + refunctioning - breaking	Boreholes	
Afar.Yearly budget growth	C	0.04	ETB	AWIEB Budget
Turkana functionality %	C	Working/total*100	%	
Turkana."2018-19 National Allocation"	C	Imported graphical function	KES	TK County Budget Review and Outlook Paper (CBROP) 2019
Turkana."Donor (Diocese) broken"	S	Diocese_schemes - Donor (Diocese) repairing	Boreholes	
Turkana."Donor (Diocese) fraction"	C	MONTECARLO(7)	unitless	Diocese of Lodwar, Turkana Water Project
Turkana."Donor (Diocese) repairing"	F	PULSE(1, 3, (Donor_repair_time/7))	Boreholes/Weeks	Diocese of Lodwar, Turkana Water Project
Turkana."Donor funds (USD)"	C	Graphical input ranging from 0 to 10000000 USD	USD	
Turkana."Donor/National Agency installation rate"	C	"Donor_funds_(USD)"*earmarked_for_new_construction/BH_unit_cost	units/year	
Turkana.access	C	Working*200*5.6/Turkana_population	unitless	Bureau of Statistics 2019 Census: ~200 HH/borehole and 5.6 people per hosuehold in Turkana

Turkana.adjusted installation target	C	IF Installation_funds > 0 THEN IF Installation_funds > 10*cost_per_installation THEN 2*baseline_installation_target ELSE baseline_installation_target ELSE 0	units/year	
Turkana.all broken	C	"Donor_(Diocese)_broken"+Broken	Boreholes	
Turkana.available hired vehicles	S	hiring - returning	vehicles	
Turkana.available owned vehicles	S	vehicle_purchasing + county_vehicles_back_from_field - expiring - vehicles_to_field	vehicles	
Turkana.available spare parts	C	Minor_Parts_in_Stock+Major_Parts_in_Stock	parts	
Turkana.baseline contracting cost	C	2500000	KES	consultant estimate
Turkana.baseline installation cost	C	5000000	KES	consultant estimate
Turkana.baseline installation target	C	26	units/year	CBROP
Turkana.baseline major parts cost	C	200000	KES	consultant estimate
Turkana.baseline minor parts cost	C	5000	KES	consultant estimate
Turkana.being born	C	birth_rate*Turkana_population/52	people/week	
Turkana.birth rate	C	27.2/1000	unitless	CIA World Data Book for Kenya
Turkana.breakdown rate	C	SAFEDIV(breakdowns, TIME)	units/week	
Turkana.breakdown threshold	C	Set using model calibration	hours	
Turkana.breakdowns	C	Hours_pumped/breakdown_threshold	Boreholes	
Turkana.breaking	F	breakdown_rate	units/week	
Turkana.Broken	S	breaking - repairing	Boreholes	
Turkana.contract completing	F	ROUND(Contractors_in_Field/(contractor_repair_time/7))	contracts/weeks	
Turkana.contracting	F	IF(Repair_Funds > contracting_cost) THEN IF(Repair_Funds > 10*contracting_cost) THEN IF(Repair_Funds > 20*contracting_cost) THEN 8*contracting_requirement*breaking ELSE 2*contracting_requirement*breaking ELSE contracting_requirement*breaking ELSE 0	contracts/weeks	
Turkana.contracting cost	C	baseline_contracting_cost*(1+Inflation)^(TIME/52)	KES	

Turkana.contracting requirement	C	MONTECARLO(10)	unitless	consultant estimate
Turkana.contracting time	C	IF contracting > 0 THEN 30 ELSE 0	days	consultant estimate
Turkana.contractor extra days	C	7	days	consultant estimate
Turkana.contractor hiring	F	ROUND(Contractors_Needed/((contracting_time+response_time)/7))	contracts/weeks	
Turkana.contractor repair time	C	repair_days+contractor_extra_days	days	
Turkana.contractor spending	F	contracting_cost*contracting	KES/weeks	
Turkana.Contractors in Field	S	contractor_hiring - contract_completing	contracts	
Turkana.Contractors Needed	S	contracting - contractor_hiring	contracts	
Turkana.cost per installation	C	(baseline_installation_cost)*(1+Inflation)^(TIME/52)	KES	
Turkana.Cost per vehicle	C	5000000	KES	consultant estimate
Turkana.County Funds	S	national_government_allocation - water_department_allocation - Other_Ministries_and_Activities	KES	
Turkana.county vehicles back from field	F	ROUND(vehicles_in_field/(repair_days/7))	vehicles/weeks	
Turkana.coverage	C	total*(200*5.6)/Turkana_population	persons	2019 Census
Turkana.death rate	C	5.2/1000	unitless	CIA World Data Book for Kenya
Turkana.Diocese schemes	F	"Donor_(Diocese)_fraction"*breaking	Boreholes/weeks	
Turkana.distance to site	C	LOGNORMAL(66, 67, 0.4, 0.41, 354)	km	Asset inventory data
Turkana.Donor funds Ksh	C	"Donor_funds_(USD)"*109.71*(1-earmarked_for_new_construction)	KES	
Turkana.Donor installing	F	IF "Donor/National_Agency_installation_funds" > 2*cost_per_installation THEN 2*installing ELSE installing	Boreholes/weeks	
Turkana.Donor repair time	C	10	days	consultant estimate
Turkana.Donor spending	F	PULSE(Donor_funds_Ksh, 1, 52)	KES/weeks	
Turkana.driving distance per day	C	150	km/day	consultant estimate
Turkana.dying	F	Turkana_population*death_rate/52	people/weeks	
Turkana.earmarked for new construction	C	Adjusted between 0-1 in interface (representing 0-100%)	unitless	
Turkana.expiring	F	PULSE(1, 260, lifetime)	vehicles/weeks	

Turkana.Flood delay	C	30	days	consultant estimate
Turkana.Flooding Factor	C	IF season = 1 THEN MONTECARLO(5) ELSE 0	unitless	
Turkana.Flooding time	C	IF Flooding_Factor > 0 THEN Flood_delay ELSE 0	days	
Turkana.functionality	C	working/total	unitless	
Turkana.hiring	F	MIN(IF(Repair_Funds > hiring_cost) THEN Target_vehicle_hiring ELSE 0, 10)	vehicles/weeks	
Turkana.hiring cost	C	repair_days*vehicle_cost_per_day	KES	
Turkana.Hours pumped	S	pumping	hours	
Turkana.Inflation	C	0.07	unitless	Central Bank of Kenya
Turkana.Insecurity delay	C	10	days	consultant estimate
Turkana.Insecurity Factor	C	MONTECARLO(10)	unitless	consultant estimate
Turkana.Insecurity time	C	IF Insecurity_Factor > 0 THEN Insecurity_delay ELSE 0	days	
Turkana.install spending	F	installing*cost_per_installation	KES/weeks	
Turkana.installation allocation	F	New_installations_fraction*(water_department_allocation+Donor_spending)	KES/weeks	
Turkana.Installation funds	S	installation_allocation - install_spending	KES	
Turkana.installation rate	C	PULSE(1, 1, SAFEDIV(52, adjusted_installation_target))	units/week	
Turkana.installing	F	installation_rate	Boreholes/weeks	
Turkana.lifetime	C	520	weeks	
Turkana.Liters per capita demand	C	9	L/person/day	consultant estimate
Turkana.major breakdown probability	C	MONTECARLO(major_breakdowns_fraction)	unitless	
Turkana.major breakdowns fraction	C	20	%	consultant estimate
Turkana.Major parts arriving	F	ROUND(Major_Parts_En_Route/(procurement_time/7))	parts/weeks	
Turkana.major parts cost	C	baseline_major_parts_cost*(1+Inflation)^(TIME/52)	KES	
Turkana.Major Parts En Route	S	purchasing_major_parts - major_parts_arriving	parts	
Turkana.Major Parts in Stock	S	major_parts_arriving - using_major_parts	parts	
Turkana.major parts per repair	C	1	parts	
Turkana.Minor parts arriving	F	ROUND(Minor_Parts_En_Route/(procurement_time/7))	parts/weeks	
Turkana.minor parts cost	C	baseline_minor_parts_cost*(1+Inflation)^(TIME/52)	KES	

Turkana.Minor Parts En Route	S	purchasing_minor_parts - minor_parts_arriving	parts	
Turkana.Minor Parts in Stock	S	minor_parts_arriving - using_minor_parts	parts	
Turkana.minor parts per repair	C	5	parts	
Turkana.national government allocation	F	"2018-19_National_Allocation"*(1+Yearly_budget_growth)^(TIME/52)	KES/weeks	
Turkana.new construction %	C	earmarked_for_new_construction*100	%	
Turkana.New installations Fraction	C	125000000/377000000	unitless	CBROP
Turkana.Other Ministries and Activities	F	national_government_allocation-water_department_allocation	KES/weeks	
Turkana.Other water expenses	F	Other_water_spending_fraction*water_department_allocation	KES/weeks	
Turkana.Other water spending fraction	C	1-Repairs_and_Maintenance_fraction-New_installations_fraction	unitless	
Turkana.procurement time	C	30	days	consultant estimate
Turkana.producing	F	weekly_pumping_hours*Total_Production_capacity	L/weeks	
Turkana.production capacity clusters	C*	Arrayed converter clustering based on pump production capacity between 4200 and 48,000	L/hrs	Asset inventory data
Turkana.production fractions	C*	Arrayed converter for the probability of a pump being in each production capacity cluster	unitless	Asset inventory data
Turkana.pumping	F	Working*weekly_pumping_hours*reliability_multiplier	hours/week	
Turkana.purchasing major parts	F	IF Repair_Funds > 0 THEN IF Major_Parts_in_Stock > 20 THEN 0 ELSE IF Repair_Funds > 100*major_parts_cost AND Major_Parts_in_Stock < 5 THEN 2*Target_purchase_rate[Major] ELSE Target_purchase_rate[Major] ELSE 0	parts/weeks	
Turkana.purchasing minor parts	F	IF Repair_Funds > 0 THEN IF Minor_Parts_in_Stock > 100 THEN 0 ELSE IF Repair_Funds > 100*minor_parts_cost AND Minor_Parts_in_Stock < 25 THEN 10*Target_purchase_rate[Minor] ELSE Target_purchase_rate[Minor] ELSE 0	parts/weeks	
Turkana.refunctioning	F	INF	Boreholes/weeks	

Turkana.reliability multiplier	C	Graphical exponential function where x axis is the number of Working boreholes and the y is between 1 and 2	unitless	
Turkana.repair and maintenance allocation	F	Repairs_and_Maintenance_fraction*(water_department_allocation+Donor_spending)	KES/weeks	
Turkana.repair days	C	2 + ROUND((distance_to_site/driving_distance_per_day)*2)	days	
Turkana.Repair Funds	S	repair_and_maintenance_allocation - vehicle_spending - spare_parts_spending - contractor_spending	KES	
Turkana.repair rate	C	county_vehicles_back_from_field+contract_completing	units/week	
Turkana.Repaired	S	repairing + Donor_(Diocese)_repairing - refunctioning	Boreholes	
Turkana.repairing	F	repair_rate	Boreholes/weeks	
Turkana.Repairs and Maintenance fraction	C	52500000/377000000	unitless	CBROP
Turkana.response time	C	time_to_find_out_about_breakdown + Insecurity_time+Flooding_time	days	
Turkana.returning	F	ROUND(available_hired_vehicles/(repair_days/7))	vehicles/week	
Turkana.season	C	Graphical input of 1 or 0 representing wet or dry season based on Kenya's long and short rains	unitless	National Drought Management Authority (NDMA)
Turkana.spare parts spending	F	(major_parts_cost*purchasing_major_parts+minor_parts_cost*purchasing_minor_parts)*(1+Inflation)^(TIME/52)	KES/weeks	
Turkana.Target purchase rate	C*	Arrayed converter: 20 for Minor Parts, 2 for Major Parts	parts/week	
Turkana.Target vehicle hiring	C	ROUND(Broken/8)	vehicles/week	
Turkana.Target vehicle purchase rate	C	1	vehicles/year	
Turkana.time to find out about breakdown	C	1	days	consultant estimate
Turkana.total	C	Working+Repaired+Broken+"Donor_(Diocese)_broken"	Boreholes	
Turkana.Total Production capacity	C	Working*(production_fractions[From_3_to_5]*production_capacity_clusters[From_3_to_5] + production_fractions[Above_5_below_10]*production_capacity_clusters[Above_5_below_10] + production_fractions[Above_10_below_20]*p	L/hr	

		roduction_capacity_clusters[Above_10_below_20] + production_fractions[Above_20]*production_capacity_clusters[Above_20])		
Turkana.Turkana population	S	being_born - dying	People	
Turkana.using	F	Liters_per_capita_demand*Turkana_population*7	L/weeks	
Turkana.using major parts	F	IF major_breakdown_probability = 1 THEN (major_parts_per_repair)*vehicles_to_field ELSE 0	parts/weeks	
Turkana.using minor parts	F	minor_parts_per_repair*vehicles_to_field	parts/weeks	
Turkana.vehicle cost per day	C	10000	KES/day	consultant estimate
Turkana.vehicle hiring time	C	IF available_owned_vehicles = 0 THEN 7 ELSE 0	days	
Turkana.vehicle purchasing	F	IF (Repair_Funds>Cost_per_vehicle) THEN (IF ((available_owned_vehicles+vehicles_in_field)<5) THEN PULSE(Target_vehicle_purchase_rate, 1, 52) ELSE 0) ELSE 0	vehicles/week	
Turkana.vehicle spending	F	(hiring_cost*hiring + Cost_per_vehicle*vehicle_purchasing)*(1+Inflation)^(TIME/52)	KES/weeks	
Turkana.vehicles in field	S	vehicles_to_field - county_vehicles_back_from_field	vehicles	
Turkana.vehicles to field	F	IF major_breakdown_probability = 1 THEN IF Major_Parts_in_Stock > 1*available_owned_vehicles AND Minor_Parts_in_Stock > 5*available_owned_vehicles THEN ROUND(available_owned_vehicles/(response_time/7)) ELSE IF Minor_Parts_in_Stock > 5*available_owned_vehicles THEN ROUND(available_owned_vehicles/(response_time/7)) ELSE 0 ELSE 0	vehicles/week	
Turkana.water department allocation	F	national_government_allocation*water_dept_budget_fraction	KES/weeks	
Turkana.water dept budget fraction	C	377000000/10770200000	CBROP	

Turkana.Water Dept Funds	S	water_department_allocation + Donor_spending - installation_allocation - repair_and_maintenance_allocation - Other_water_expenses	KES	
Turkana.water stored	S	producing - using	L	
Turkana.weekly pumping hours	C	Imported graphical function	Hours/week	Sensor data
Turkana.Working	S	Installing + Donor_installing + refunctioning - breaking	Boreholes	
Turkana.Yearly budget growth	C	0.06	unitless	

References

Central Statistical Agency, 2013. Population Projection at Wereda Level from 2014-2017. Federal Democratic Republic of Ethiopia.

Climate-Data.org, 2019. Climate data for cities worldwide [WWW Document]. URL https://en.climate-data.org/ (accessed 10.2.19).

Kenya National Bureau of Statistics, 2019. Volume II: Distribution of Population by Administrative Units (Census Report), 2019 Kenya Population and Housing Census.

mWater [WWW Document], 2021. mWater. URL https://www.mwater.co/ (accessed 12.3.21).

WHO, UNICEF, 2020. JMP [WWW Document]. JMP Households Data. URL https://washdata.org/data/household#!/ (accessed 12.3.21).