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1 **Overview and first results of ecological monitoring at the artificial watershed Chicken**
2 **Creek (Germany)**
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Abstract

An artificial catchment of 6 ha was established in the Lusatian lignite mining district (Germany). A comprehensive monitoring program was launched immediately after the construction was finished in autumn 2005. The setup of the monitoring and first results of the period 2005-2008 are presented in this paper. From the monitoring measurements it is obvious that the establishing ecosystem is highly dynamic. In addition, important components of the artificially created system are governed by characteristic, often seasonal trends. These observations make clear that the performance of the artificial catchment is generally in agreement with naturally formed watersheds but the system is still in a very initial phase of establishment. Especially, soil properties, hydrological behaviour and vegetation succession illustrate that the development of the system started very close to “point zero”. Even if the construction of the site itself left different initial structures the starting conditions of the catchment can be characterized in general as relatively homogenous in comparison with other close to “point zero” systems. However, new structures emerging at the surface of the site but also in the subsurface differentiated the system significantly soon after “point zero”.

Keywords

artificial catchment, environmental monitoring, ecosystem development, initial ecosystem, ecosystem succession

1. Introduction

In 2007 the German-Swiss Transregional Collaborative Research Centre (SFB/TRR 38) “Structures and processes of the initial ecosystem development phase in an artificial water catchment” was launched as a collaboration of the Brandenburg University of Technology, Cottbus (BTU), the Technische Universität München (TUM) and the Swiss Federal Institute of Technology Zurich (ETH). The overall objective of this interdisciplinary project is to elucidate the role of structures and processes during the initial establishment of an ecosystem. The central hypothesis of the project assumes that initial patterns substantially define and shape the development and later stages of an ecosystem. The central objectives of this collaborative project are (1) to reveal which abiotic and biotic structures and processes control the initial phase of ecosystem development; (2) to investigate the interactions existing between both abiotic and biotic processes and patterns in the initial phase; (3) to characterize differences between processes and patterns of initial systems compared to mature ecosystems; (4) to derive and define different stages during this early ecosystem development; and (5) to find indicators that allow the transfer of results to other ecosystems in an initial stage.

The project uses an artificially built catchment with defined initial and boundary conditions. This paper describes the setup of the comprehensive ecosystem monitoring that was initiated immediately after the completion of the catchment in autumn 2005 and its first results.

2. Site description

The artificial catchment was constructed in the Lusatian lignite district (Brandenburg, Germany). A general overview of the technical construction works is given by Kendzia et al. (2008). The research site is located close to the city of Cottbus (about 150 km south east of

1 Berlin) in the active lignite mine “*Welzow-Süd*” (Fig. 1). This opencast mine is situated in the
2 north-eastern part of Germany near the Polish border in a region characterized by a temperate
3 climate with a sub-continental character. The mean annual temperature is 9.3°C, the annual
4 precipitation 559 mm (data from DWD meteorological station Cottbus for the period 1971-
5 2000).

6 The catchment with an area of about 6 ha (400 m x 150 m) has been laid out as a slight slope
7 with an altitude difference of about 15 m along the main axis and an average inclination of
8 3.5 % (Fig. 2). The exposition is SE. In Fig. 3 the internal construction of the site is illustrated
9 by schematic cross sections showing the clay layer and the covering sandy layer. The
10 construction works were carried out by large mining devices such as conveyor belt systems
11 with bucket wheel excavators and a coupled stacker. A 1 m to 3 m thick base layer consisting
12 of Tertiary clay was dumped and flattened as a barrier for seepage water. The surface of the
13 clay layer was shaped as a shallow basin ascending from the centre to the edges to form the
14 subsurface boundary for the catchment (Fig. 4). On top of the clay layer a sandy substrate
15 with a total volume of 117,500 m³ (Kendzia et al., 2008) was dumped by stacker with a
16 thickness of up to 3.5 m. The sandy material stems from Pleistocene sediments taken from the
17 fore-field of the mine where it was deposited during the Saale-glacial period as a terminal
18 moraine. In the underground section of the lower part of the catchment additional clay walls
19 were constructed on top of the clay layer running transversal to the slope, both as a
20 stabilization barrier to prevent the sandy substrates from sliding downhill upon the clay layer,
21 and additionally to form a central discharge unit for groundwater. Finally, the surface of the
22 site was flattened and homogenized using rails pulled by tractors. Surface structures like
23 tracks of bulldozers or of other vehicles were removed widely so that the surface had only
24 very few structures in the beginning of the ecosystem development. However, it cannot be
25 excluded that also this final measure caused new small scale structures or that previous

1 structures were only covered by a thin layer of sandy material. Further details on the
2 catchment construction are described by Gerwin et al. (2009a+b).

3 The construction plan allowed for the establishment of a small pond at the lowest part of the
4 catchment with a diameter of around 70 m and a maximum initial depth of 3 m. A clay wall at
5 the southern side of the pond defines the lower border of the catchment with one single outlet.
6 The catchment can be divided into three major sections: (1) the backslope area which covers
7 most of the site, (2) the footslope with a steeper inclination, and (3) the pond basin with the
8 single outlet of the watershed (Fig. 4). The site is left for an unrestricted and unmanaged
9 succession but was fenced in completely to avoid vandalism and disturbance by the frequent
10 game in the region. Neither amelioration measures such as fertilization and liming nor
11 planting or sowing have been applied. Erosion and other surface forming processes are
12 allowed to ensue without restriction.

14 **3. Monitoring concept**

15 Lovett et al. (2007) pointed out the significance of monitoring as a crucial part of
16 environmental sciences in general. In this regard a comprehensive observation program was
17 launched to monitor the key components and compartments of the catchment. Basic
18 monitoring started immediately after the end of construction works in 2005 and was then
19 considerably intensified with the start of the SFB/TRR 38 in summer 2007. Within the
20 catchment monitoring of environmental parameters is carried out to measure meteorological,
21 hydrologic and soil conditions (Tab. 1, Fig. 5). In addition, specific monitoring programs are
22 carried out including vegetation and soil fauna as well as limnological parameters within the
23 pond.

Characterization of initial site conditions

In a first step the site was subdivided by a regular grid of 20 m x 20 m using GPS technique. Each grid point was marked by a small flag for a permanent easy orientation within the catchment with rows in W-E direction numbered from 1 to 7 and lines in N-S direction labeled with A to V.

Soil sampling was carried out to characterize main substrate properties and its spatial (horizontal and vertical) distribution within the catchment. Samples were taken between October 2005 and April 2006 at all grid points at two depths (0-30 cm and 30-100 cm). In a 40 m x 40 m grid additional samples were taken from depths of 100-150 cm, 150-200 cm and from 2 m depth down to the clay layer. Further, during the construction phase, samples were taken from eleven cones of the dumped substrates in January 2005. These samples were analyzed for pH, electrical conductivity (EC), texture, total content of carbon, nitrogen and sulphur, organic carbon content and lime content. The cone samples were additionally analyzed for actual cation exchange capacity (CEC), oxides and hydroxides of iron and aluminum using extractions with dithionite (Fe_d , Al_d) and oxalate (Fe_o , Al_o), total content of Fe and Al (Fe_T , Al_T) using high temperature and high pressure digestion with HNO_3 , and composition of the clay fraction (XRD analysis). Main results of this are given in Tab. 2. Soil sampling to study changes of the substrate properties is planned to be repeated after 5 years.

As this first soil sampling proved the Quaternary substrate to be relatively homogenous both spatially and with depth, all further installations were oriented along the basic 20 m x 20 m grid.

Meteorology

Two weather stations are operated in the catchment (Fig. 5). Weather station 1 in the upper part of the back slope area is used for the hourly registration of basic meteorological data. Weather station 2 located in the foot slope area provides more detailed data about wind speed, air temperature and humidity at 3 elevations above ground. Downward and upward directed as well as short-wave and long-wave radiation components are measured separately. In addition, soil temperature and heat flux is recorded. As atmospheric deposition might be an important source for nutrient input, bulk deposition is sampled in a grid-design using 18 samplers throughout the catchment. The gathered data are used to calculate annual element inputs (Schaaf 2004) that can be integrated into element flux models.

Hydrology

Groundwater levels are recorded at 25 sites within the catchment (Fig. 5), 9 of them equipped with automatically registering pressure transducers (divers). For installing the groundwater observation wells boreholes were drilled manually down to the clay layer. The wells are composed of 2" (50.8 mm) PE pipes with a 1 m well screen (slot width 0.3 mm) at the bottom. Two main weirs were installed to measure water fluxes. At the outlet of the subsurface clay walls above the pond, a weir (weir 1) was installed during the construction of the catchment. This weir mainly registers groundwater flow on top of the subsurface clay layer by means of a tipping counter and a V-notch profile. Another weir (weir 2) was placed at the outlet of the pond representing the total discharge point for the whole watershed. For a reduction of measuring inaccuracy over the whole measuring range different measurement procedures are applied here. Characteristically, very low flow rates are regarded as important parts of the water balance. These low discharge rates up to 1 l s^{-1} are registered by means of a

tipping counter. Higher fluxes up to approx. 4 l s^{-1} caused by increasing water levels of the pond are measured at an adequate V-notch weir. Two additional rectangular profiles with larger dimensions complete this complex weir and allow discharge rates up to 110 l s^{-1} and additional 120 l s^{-1} , respectively. In two main erosion gullies flumes are installed to register both the continuous base flow from groundwater discharge and episodic run-off events in these structures. Both weirs and one of the flumes are equipped with automated water sampling units taking daily samples for water quality analyzes.

Soil

Soil solution is sampled at four soil funnels (Fig. 5) that were excavated down to the saturated layer in 2-2.5 m depth by hand and stabilized with a lining of PE rings with a diameter of 1m. From these pits boron silicate glass suction plates ($\varnothing 10 \text{ cm}$) were installed into the soil in 2-3 depths. Soil solution is collected using a permanent pressure head of -10 kPa and sampled every two weeks. Additionally, automated TDR probes and tensiometers were installed from these soil funnels to measure soil moisture conditions. The sensors are installed in the same depths as the suction plates. Data are logged automatically. Soil moisture is additionally monitored by means of 14 permanently installed pipes for a PR2-profile probe and 20 tensiometers.

Surface structures

For the monitoring of changes in the surface structures of the catchment aerial images are taken regularly. First aerial photos were taken from a helicopter in 2006 and 2007. Since spring 2008 a micro-drone equipped with a digital camera is used. A characteristic feature of

1 the microdrone is the navigation by GPS that allows way-point-navigation and programmed
2 flights and enables the microdrone to hold its position. The height of the flights varies
3 between 40 m and 80 m depending on the purpose of the monitoring. A complete aerial photo
4 of the total catchment is composed of a mosaic of approx. 20 images which have to be geo-
5 referenced and rectified for further use in GIS (Fig. 6). Additional aerial photographs taken
6 monthly since the start of the site construction in 2004 are provided by Vattenfall Europe
7 Mining AG.

9 **Vegetation**

10 The amount of viable seeds in the substrate used for the catchment construction (soil seed
11 bank) was analysed in 108 soil samples taken in autumn 2005 within the 20 m x 20 m regular
12 grid (Fig. 5) (for method see Fischer 1987). As part of the geobotanical monitoring program
13 the transport of plant seeds by wind was assessed. Specific traps consisting of a disposable
14 Petri dish with a filter paper brushed with bag balm are exposed to catch wind-transported
15 seeds at a height of 30 cm. Altogether 55 traps were installed along the border of the
16 catchment. Since 2005, the initial vegetation development of the study site has been recording
17 annually. The 119 assessment plots are assigned to the regular grid points. Each grid point
18 denotes the centre of a quadrat plot of 25 m². In 2005, the vegetation was assessed directly
19 after finishing the catchment area construction works. In the following years vegetation
20 records have been repeated regularly in summer.

22 **4. Results of monitoring investigations**

1 First results (2005-2008) of meteorological, hydrological and pedological monitoring as well
2 as data of water quality are presented to illustrate the very initial development of the artificial
3 catchment Chicken Creek. For further information and the complete datasets of the ongoing
4 monitoring see the newly established series of books “Ecosystem Development” (ISSN 1867-
5 7800, Schaaf et al. 2010a) which is available online at www.tu-cottbus.de/sfb_trr from
6 autumn 2010.

7 During the first years of development a large number of different both abiotic and biotic
8 surface structures emerged. Abiotic structures are e.g. the very soon developing erosion
9 gullies, sedimentation areas and the groundwater body in the subsurface whereas biotic
10 structures are represented e.g. by vegetation patterns. In this context, soil crusts can be seen as
11 the connection between early abiotic and biotic structures. They frequently cover the first
12 millimetres of the soil. Cyanobacteria, green algae and mosses are often one of the first
13 colonizers and forming biological soil crusts (Spröte et al. 2010).

14 The mean annual air temperatures of the years 2006, 2007, and 2008 for the Chicken Creek
15 catchment were 10.9 °C, 11.2 °C, and 10.9 °C, respectively. These first three years of the
16 monitoring program were warmer compared to the long-term annual mean of 9.3°C. The
17 distribution of precipitation showed a high variability between the different months which is
18 typical for Central European climate conditions (Fig. 7). The largest precipitation sum in this
19 observation period was recorded in May 2007 with 185 mm. The annual sums of precipitation
20 for the Chicken Creek catchment of the observed three years were 349 mm, 595 mm, and
21 587 mm, respectively. In general, at the Chicken Creek catchment the western wind direction
22 is clearly dominating (Fig. 8). The most important direction is southwest with an accentuation
23 of the WSW direction. Wind velocities of the Beaufort classes 2 and 3 are predominant in this
24 area (Fig. 8). The maximum wind speed so far was registered on January, 19th 2007 at 01:00

1 a.m. The winter storm “Kyrill” reached the site with a registered velocity of 17.1 m s^{-1}
2 (corresponding to Beaufort number 7).

3 The level of the groundwater tables in the artificial catchment shows typical seasonal
4 fluctuations and is clearly depending on climatic parameters (Fig. 9). The climatic water
5 balance (calculated for each hydrological year) was determined as the difference between
6 precipitation (corrected after Richter, 1995) and potential evapotranspiration (expressed as
7 reference grassland evaporation after Allen et al., 1994). The water levels in the groundwater
8 gauges reached their minima and maxima parallel to the cumulative climatic water balance. In
9 general, the groundwater levels increased over the observation period at most of the gauges.
10 In contrast, from summer 2007 on gauge N4 showed a different behaviour (Fig. 9) which can
11 most probably be explained by a punctual exfiltration of groundwater to the surface of the
12 deeply eroded main gully close to this gauge. The gully is incised down to the groundwater
13 table in this part of the catchment.

14 Also the pond level clearly correlates with precipitation (Fig. 10). The pond filled completely
15 for the first time immediately after snow melt in January 2006. Surface run-off was promoted
16 by frozen soil at that time. The pond rose to a high level during this event as the construction
17 of the outlet weir was not yet finished. Changes in the pond level are strongly dependent on
18 episodic surface run-off from the watershed after high precipitation events.

19 The results of the soil sampling in autumn 2005 shortly after the completion of the
20 construction works characterize the Quaternary soil substrates as sands to loamy sands
21 containing low amounts of carbonate (Tab. 2). The soil substrates show textural differences
22 between the western and the eastern part of the catchment due to the fact that the substrates
23 were dumped in two different periods during the construction process (Schaaf 2010a). In the
24 NE part of the catchment pure sands dominate whereas the SW part has more loamy sands
25 (Fig. 11a). These differences reflect variations in the post-glacial surface layer of the

1 landscape that was used for construction. Due to the carbonate content the pH (H₂O) values
2 are weakly alkaline or neutral (Fig. 11b). Total carbon content in the substrate is very
3 uniformly low, as expected. About two thirds of it are due to the carbonate content (Fig. 11c).
4 The low contents of organic carbon (1.6–2.2 mg g⁻¹) and extractable pedogenic oxides and
5 hydroxides underline the initial state of the soil (Fig. 11d).

6 In general, pH values in all water samples taken from the weirs and from one of the flumes
7 varied between 7.0 and 8.5 (Fig. 12a). Abrupt drops and increases in pH values of up to one
8 pH unit per day can be observed. This is most pronounced for the flume samples, but also the
9 weir samples follow similar trends. Total ion concentrations in water samples from the three
10 sampling sites are in the order flume > weir 1 > weir 2 (at the outlet of the catchment
11 underneath the pond) as indicated by EC (Fig. 12b). The pond water measured at weir 2
12 shows only little temporal variation with regard to EC. In contrast, considerable short-term
13 peaks in EC of up to $\pm 1500 \mu\text{S cm}^{-1}$ per day are observed in weir 1 and flume samples. EC
14 values of weir 1 samples show typical temporal patterns with increasing values during
15 drought periods and sharp drops after precipitation events. Main components in all water
16 samples are Ca²⁺, SO₄²⁻, Mg²⁺, HCO₃⁻ and DOC. These concentrations follow again the order
17 flume > weir 1 > weir 2 (Schaaf 2010b). Ammonium concentrations show a seasonal trend,
18 most pronounced in the flume samples, with higher values during summer months. Also the
19 weir samples show higher NH₄⁺ concentrations in summer 2008 compared to 2007.
20 Concentrations of Al³⁺, Fe³⁺ and NO₃⁻ were below detection limits (< 0.01 mmol L⁻¹) in all
21 samples throughout the sampling period.

22 The series of aerial photographs taken by Vattenfall Europe Mining AG as well as by
23 microdrone flights reflects very well the development of the erosion gully network in a short
24 period of time. Fig. 13 illustrates this fast process which was triggered significantly by a
25 number of heavy rainfall events in 2006. This network of gullies became denser in the

1 following years, however, the general shape obviously did not change during the observation
2 period. The erosion gullies are new structures within the system which influence in turn the
3 further development, e.g. the establishment of vegetation patterns.

4 Soil seed bank analysis and the monitoring proved that the Chicken Creek material was poor
5 in diaspores at the beginning but not totally free of it. The vegetation succession started in
6 2005 on the catchment substrate containing a low number of viable seeds and with a low
7 number of seeds imported by the wind (Gerwin et al. 2009b). The vegetation monitoring on
8 119 5 m x 5 m grid plots documented clearly the rapidly increasing vegetation cover and
9 number of plant species since 2005. In the first year a total of 18 plant species was found. The
10 number of species increased very fast up to 136 in 2008. Specific distribution patterns
11 developed both in space and in time. In each of the years the two most dominant plant species
12 were not the same: in 2005 *Cirsium arvense* and *Chenopodium album*, in 2006 *Ch. album* and
13 *Conyza canadensis*, in 2007 *C. canadensis* and *Echinochloa crus-galli*, and in 2008 *Trifolium*
14 *arvense* with *Tussilago farfara*. The annual species *Chenopodium album* (Chenopodiaceae)
15 reached its maximum distribution and cover already in 2006 (Fig. 14a). The invasive annual
16 to biannual *Conyza canadensis* (Asteraceae) was prevalent all over the site in 2006 and 2007
17 with high covers in the eastern part of the catchment. In 2008 its importance decreased
18 significantly (Fig. 14b) and *Trifolium arvense* (Fabaceae) as another annual plant species
19 gained dominance starting in 2007. In 2008, this species built up very dense patches
20 especially at the upper western part of the study site (Fig. 14c). Pioneer tree species are *Pinus*
21 *sylvestris* (Pinaceae), *Salix caprea*, *S.* (Saliaceae) and *Robinia pseudoacacia* (Fabaceae). As a
22 fast-growing tree *Robinia pseudoacacia* (Fabaceae) appeared very rapidly and was already
23 present by a total of 88 single individuals in 2008. The symbiotical nitrogen-fixation by the
24 Fabaceae *Robinia pseudoacacia* and *Trifolium arvensis* is an important N input pathway into

1 the nutrient limited sandy soils. The nitrogen is integrated into the biogeochemical cycle and
2 improves the soil conditions to favour late successional plant species.

3 4 **5. Conclusions**

5 The results of the ongoing monitoring at the Chicken Creek catchment underline that the
6 system is in its very initial phase of establishment. Especially, soil properties and hydrological
7 behaviour illustrate that the development of the system started very close to “point zero”. This
8 is also shown by the very low vegetation cover and total number of plant species in the
9 beginning of the observation period. Important components of the artificially created system
10 are governed by characteristic, often seasonal trends. For example, groundwater levels and the
11 water level of the pond show seasonal fluctuations which is in good agreement with other,
12 naturally formed watersheds.

13 Tischew and Kirmer (2007) introduced different typical pathways of succession in post-
14 mining landscapes of eastern Germany. They pointed out that the direction of primary
15 succession in post-mining landscapes of eastern Germany highly depends on soil properties
16 like pH values and soil moisture content. However, the sites described in their study were not
17 influenced by high groundwater levels which is in contrast to the situation at the Chicken
18 Creek site. Therefore, direct comparisons of the first results of monitoring at Chicken Creek
19 with other studies regarding primary succession, e.g. dealing with re-vegetation of former
20 mine sites in the region, are difficult. The artificial catchment offers unique site properties
21 (e.g. with regard to the high groundwater levels) which cannot be found frequently in other
22 post-mining landscapes. The vegetation succession is for that reason by far faster compared
23 with other reclamation sites in post-mining landscapes but is in principal in agreement with
24 general successional pathways. Especially annual plant species are of importance in the

1 beginning of primary successions in post-mining landscapes (Jochimsen 2001). However, the
2 number of plant species appearing after only five years of development in the Chicken Creek
3 catchment exceeds by far the numbers of plant species at young sites in post-mining
4 landscapes in Lusatia presented by Wiegand and Felinks (2001). These authors came to the
5 conclusion that especially early stages of ecosystem development can be extremely species
6 rich in these landscapes which is obviously true also for the Chicken Creek site. However, the
7 Chicken Creek catchment offers comparably very advantageous site conditions for pioneering
8 plant species probably due to the good water availability throughout the year.

9 The first preliminary results of the comprehensive monitoring program presented in this paper
10 indicate gradual relations between different structures after five years of development. For
11 example, in the beginning the vegetation patch formation was mainly driven by chance i.e.
12 which diaspores of which species emerge first and at random places. After five years of
13 development vegetation patches appear (Fig. 14, *Conyza canadensis* and *Trifolium arvense*)
14 probably reflecting certain differences in site factors, e.g. slight differences in sand or organic
15 carbon content (Fig. 11) which certainly existed also in this visually homogeneous site in the
16 beginning. The analysis of relations between different structures of the system will be one of
17 the central objectives of the research project in the following periods. Therefore, a thorough
18 analysis of these interrelationships and feedbacks will be presented later by means of a
19 structure and process model of the developing catchment (Maurer et al. 2009).

20 In summary, the results of the monitoring during the first years of ecosystem development
21 revealed a very rapid and dynamic development. Similar experiences with the initial
22 development of naturally formed virgin ecosystems were described by Friðriksson (2005) by
23 the example of the Surtsey island (Iceland) in the Northern Atlantic. These findings agree
24 very well with the hypotheses of the underlying research project that the establishment of new

1 structures and patterns and the differentiation of separated phases of ecosystem development
2 can be investigated within a short period of time.

3 Since the development of the catchment started under relatively homogenous conditions,
4 especially concerning the surface which did not show any obvious structures like vegetation
5 patterns or areas with different soil moisture conditions, the monitoring program was
6 established along a regular grid. During the first five years emerging new structures at the
7 surface of the site but also in the subsurface differentiated the system significantly. The
8 relatively unstructured system with a comparably low degree of complexity in the beginning
9 gives way to a more structured system with developing patches and patterns. The interesting
10 question and the demanding task for future analyses will be the explanation of these
11 developing new structures by using the initial properties of the system at “point zero”.
12 Further, the evolving interactions between these different structures have to be taken into
13 account when explaining the behaviour of the system at the catchment scale.

14 The monitoring program currently is and will be adapted to this differentiation and future
15 developments. Several of the newly emerging structures like vegetation patches or erosion
16 gullies are at a scale that is not represented completely by the 20 m x 20 m grid. Therefore,
17 the monitoring concept has been developed to cover these structures and patterns (e.g.
18 measurements along gradients in vegetation cover or surface soil texture) without leaving the
19 first approach completely to ensure long-term observation datasets. In addition, more and
20 more measurements will be carried out by individual subprojects of the research centre in the
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3

Figure captions

Fig. 1: Location of the artificial catchment Chicken Creek

Fig. 2: Aerial photograph of the artificial catchment Chicken Creek in 2006

Fig. 3: Schematic cross section of the artificial catchment: a) SW – NE section, b) NW – SE section

Fig. 4: Map of the artificial catchment Chicken Creek

Fig. 5: Overview of the installed monitoring technique at the Chicken Creek catchment

Fig. 6: Aerial photograph of the artificial catchment (mosaic picture from microdrone flight July 2009)

Fig. 7: Temperature and precipitation registered at the Chicken Creek catchment (weather station 1; daily averages) (period 09/2005-07/2009)

Fig. 8: Wind properties registered at the Chicken Creek catchment: a) Relative frequency of wind directions; b) classification of wind velocity (daily averages)

Fig. 9: Trends of groundwater levels at the artificial catchment over the observation period in comparison with the climatic water balance

Fig. 10: Water level of the pond over the observation period

Fig. 11: Soil properties of the artificial catchment at the beginning of system development (soil sampling in autumn 2005): a) sand content, b) pH (H₂O) value, c) calcium carbonate content, and d) organic carbon content in 0-30 cm soil depth, respectively.

Fig. 12: Composition of water samples from weirs and flume: a) pH-values; b) electrical conductivity (EC); grey bars indicate daily precipitation

Fig. 13: Precipitation and development of the erosion gully network during the first three years: information from aerial photographs of the years 2005-2008 (based on photographs taken by Vattenfall Europe Mining AG)

Fig. 14: Distribution of plant species and cover (%) at the artificial catchment in the years 2005-2008: a) *Chenopodium album* b) *Conyza canadensis*, and c) *Trifolium arvense* (size of the dark dots represent the degrees of coverage: smallest dots. 0.1% cover, small dots 0.5%, medium sizes dots: 1-10% with each dot larger, >10% dots in 5% steps increasing with biggest dots 30 %); light grey dot: no cover)

1 Tab. 1: Monitoring installations and measured parameters

Quantity	Instrument	Number	Operating mode	Installation levels	Comment
meteorological data	weather station (1)	1	automatic, hourly recorded data sets	air temperature, wind, humidity and radiation in 2 m, precipitation in 1 m, soil temperature in -0.05 m and -0.1 m	installed since autumn 2005
	weather station (2)	1	automatic, data sets are recorded every 10 min.	air temperature, wind, humidity in 0.5 m, 2 m, 10 m, net radiation in 2 m, precipitation in 1 m and 0 m, soil temperature in -0.05 m and 0.1 m, soil heat flux in -0.2 m	installed since spring 2008
deposition	bulk precipitation sampler	18	manual sampling every 14 days	1 m	installed since July 2007; samples are analyzed for pH (Beckmann pH34 glass electrode and WTW pH537), electrical conductivity (EC; Hanna HI 8733 and WTW LF537) and concentrations of

					Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Fe^{3+} , Al^{3+} (ICP-OES Unicam 701 and Thermo Scientific iCAP 6000), NO_3^- , SO_4^{2-} , Cl^- (IC Dionex 5000), NH_4^+ (Rapid Flow Analyzer Alpkem), DOC, TOC, TIC and TN (Shimadzu TOC-5000 and VCPH+TNM-1)
groundwater level	groundwater gauges	25	manual measurement once a month 9 gauges are equipped with automatic pressure transducers (hourly measurement)	drilled down to the clay layer	installed within a 40 m x 60 m grid since autumn 2005, additional gauges were installed in the following years for specific questions
soil water	PR2 probes	14	manual measurement every 14 days	measurement in the following soil depths: 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.6 m, 1.0 m	installed within a 40 m x 60 m grid close to the groundwater gauges since April 2008
	tensiometers	10	manual measurement every 14 days	1.0 m and 2.0 m soil depth	installed within a 60 m x 80 m grid close to the PR2 probes since May

					2008
	TDR probes	12	automatic hourly measurement	0.1 m, 0.3 m, 0.5 m, 0.8 m soil depth	installed in 4 permanent reinforced soil funnels summer 2008
	tensiometers	12	automatic hourly measurement	0.3 m, 0.5 m, 0.8 m, 1.5 m soil depth	installed in 4 permanent reinforced soil funnels since summer 2008
soil solution	boron silicate glass suction plates	14	automatic suction control, sampling over a period of 14 days	0.3 m, 0.8 m, 1.5 m soil depth	installed in 4 permanent reinforced soil funnels since November 2007; sample analysis according to bulk precipitation samples above
discharge	weir (1)	1	combined weir geometry with tipping counter, pressure transducer for measuring water level	installed above the pond at the outlet of the subsurface clay wall	installed since 2005; measuring groundwater discharge
	weir (2)	1	combined weir geometry with tipping counter, pressure transducer for measuring water level	installed at the outlet of the pond	installed 2006; measuring discharge from the total catchment at the outlet of the pond

	flumes	2	ultrasonic sensor (measurement of water level) combined with tipping counter (at 1 flume)	installed in (1) the main erosion gully and in one further gully	installed spring 2007 and autumn 2007 measuring base flow in gullies and surface runoff events
water chemistry	water samplers	3	automatic water sampling once a day	installed at the two weirs and the flume in the main erosion gully	installed since June 2007 and May 2008 (flume); daily samples are analyzed for pH and EC; biweekly mixed samples are analyzed according to bulk precipitation samples above

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- 1 Tab. 2: Properties of initial soils at the artificial catchment (mean values (m) and standard deviation (s) of soil parameters from the grid sampling;
- 2 number of samples in 0-30 cm: 124, 30-100 cm: 120, 100-150 cm: 29, 150-200 cm: 28, >200 cm: 18)

depth	pH	EC	gravel	sand	silt	clay	C _T	C _{org.}	N _T	S _T	CaCO ₃
	(H ₂ O)	μS cm ⁻¹	%	%	%	%	mg g ⁻¹	mg g ⁻¹	mg g ⁻¹	mg g ⁻¹	%
0-30 cm											
m	8.05	207.4	14.5	84.8	9.1	6.1	2.7	1.6	0.1	0.2	0.87
s	0.43	293.6	6.6	5.4	3.4	2.1	1.5	1.0	<0.01	0.1	0.66
30-100 cm											
m	8.02	187.8	10.7	82.4	10.3	7.3	3.3	2.2	0.1	0.2	0.94
s	0.46	131.8	5.8	5.7	3.5	2.5	1.7	1.2	<0.01	0.2	0.62
100-150 cm											
m	7.82	238.9	7.8	82.2	9.9	7.9	3.4	2.1	0.1	0.2	1.09
s	0.49	99.4	3.4	5.4	2.7	2.5	1.7	1.2	<0.01	0.2	0.85

150-200 cm											
m	7.73	231.8	12.4	82.9	9.6	7.5	3.0	2.0	0.1	0.2	0.89
s	0.66	111.0	3.2	4.8	2.5	2.2	1.6	1.2	<0.01	0.2	0.63
>200 cm											
m	7.8	257.2	9.3	83.8	8.9	7.3	3.1	1.9	0.1	0.2	1.0
s	0.45	111.0	4.3	4.4	2.0	1.9	1.2	0.9	<0.01	0.1	0.6
total											
m	7.87	247.9	12.2	83.4	9.7	6.9	3.1	1.9	0.1	0.2	0.93
s	0.72	12.1	6.0	5.6	3.3	2.4	1.6	1.2	<0.1	0.2	0.67

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•	20 m x 20 m grid point
input data	
🚩	weather station
🗑️	Dry/wet deposition sampler
⊙	bulk immission sampler
hydrology	
⊙	groundwater gauges
◁	flow rate indicators (flumes)
◁	weirs I + II
○	water gauge lake
soil moisture	
✦	soil moisture probes (PR2 profile)
✦	tensiometers
water chemistry	
○	soil funnels
🗑️	automatic water samplers

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