Answer to the interactive comment of G. Ferguson:

The article "Thermal Management of an Urban Groundwater Body" by Epting and Huggenberger provides a cursory overview of the thermal state of the Basel's subsurface. However, it falls short of the ambitious goal of providing a thermal management plan. The manuscript does not build upon previous work as much as it could and the physical processes are not dealt with as rigorously as they are in other works.

- ➔ We agree that the goal of providing a thermal management plan within this manuscript is ambitious. However, the manuscript illustrates a first approach (pilot project) and necessary tools for the thermal management of the shallow aquifer in Basel.
  The manuscript describes the thermal state of the investigated groundwater body and allows the localization and quantification of the main heat-sources, including the various thermal groundwater users as well as major buildings constructed into the saturated zone. Results facilitate to allocate areas within the groundwater body where qualitative problems caused by elevated temperatures might occur and how these areas could be managed and used in the future. Furthermore, the setup of the heat transport model allowed evaluating and describing the spatiotemporal variations within the thermal groundwater flow regime and to develop and evaluate future use scenarios and mitigation strategies. Such tools to our opinion are the basis for the optimization of future thermal groundwater use and to effectively use the "thermal pollution" within the investigated groundwater body. Insofar we provide first solutions how thermal energy within the shallow groundwater body of the Basel area can effectively be used.
  The goal of our contribution is to visualize the effect of thermal pollution within an industrial area of the city of Basel and to contribute in the debate on the potential to use "wasted energy". Furthermore, this pilot study allows sensitizing the public authorities and local industry regarding possibilities for a sustainable use of urban groundwater bodies.
  Although, the area of the investigated groundwater body is too small to develop a comprehensive thermal management of the whole city, we think that in many urban areas, tailored solutions have to be developed. In areas of Basel "wasted energy" could be used "in situ", or at least nearby and thermal energy could be temporally stored within the clays or marls of the underlying formations and be used during winter months. Our work gives a solid base for the planning of such thermal use systems. In addition, the sustainable use of groundwater resources requires the definition of goals to derive measures to minimize thermal pollution of the shallow groundwater in urban areas (see next section). In this sense, we also proposed some modification in the text to clarify the points made by the reviewer (see below).

- ➔ Comment on statement "cursory overview":
  To the best of our knowledge regarding heat transport in a shallow aquifer which is characterized by high permeable unconsolidated gravel deposits and multiple groundwater users: (1) the dataset from the urbanized and industrialized Basel area is currently one of the most detailed and comprehensive ones available; (2) there is no previous work that has attempted to investigate the combined impact of the different natural and anthropogenic impacts on urban thermal groundwater regimes; and (3) no study exists where a monitoring system (multilevel observation wells with temperature sensors in the saturated and unsaturated zone) was installed to study specific thermal processes.

- ➔ Comment on statement "physical processes":
  We also want to emphasize that the work was prepared for direct implementation of thermal groundwater management for the investigated aquifer in Basel. The pilot project focused on capturing the most relevant thermal boundary conditions. Additional investigations e.g. to study the physical processes taking place within the unsaturated zone, especially concerning the influence of the sewage system and impacts of subsurface construction (see also manuscript) require the elaborate set-up of measurement devices.

➔ The references the reviewer presents (several of them are cited within the manuscript) mainly deal with work that was performed either in: (1) deep aquifers (>100m); (2) solid rock aquifers; or (3) confined aquifers. In contrary to the Basel case study, thermal regimes within shallow high permeable unconsolidated gravel deposits are not the issue of the listed references.

➔ We suggest to change the title to:
"Development of tools for the thermal management of an unconsolidated shallow urban groundwater body"
Change the abstract to:
(p. 7182, l.2) *This study presents a concept for the sustainable thermal use of an urban groundwater body.*
(p. 7182, l.16) *Subsequently, first implications for management strategies are discussed, including minimizing …*
Amend the discussion:
(p.7205, l.12): *(i.e. seasonal storage of heat in deeper geological formations / Rhinegraben Molasses below the unconsolidated sediments which are characterized by low permeability).*
(p.7205, l.17): *Considering future industrial development within the area, the implementation of balanced heating and cooling facilities could be more effective in finding local solutions than changing aquifer use policies for an entire region.*
Amend the conclusions:
(p.7206, l.4): *This study illustrates a conceptual approach and the development of tools necessary for the thermal management of shallow aquifers within high permeable unconsolidated gravel deposits. Results allow localizing and quantifying the main heat-sources within the investigated groundwater body, including the impact of thermal groundwater use and large scale buildings constructed into the saturated zone. The identification of areas with elevated temperatures within the groundwater body is the basis for the development and evaluation of future use scenarios and mitigation strategies in regard of groundwater quality and climate change issues. Furthermore, the now available tools allow to visualize the effect of "thermal pollution" and to contribute to the debate on the potential use of "wasted energy" in urbanized areas.*

The simulations produced in this study only consider infrastructure that extend beneath the water table as heat sources. It is not clear what percentage of buildings and other structures do this but this will result in an underestimation of heat flow from these sources. Sources from the surface and within the unsaturated zone will penetrate downward as well, in most cases nearly as effectively as those in the saturated zone. Thermal diffusivity does not vary a huge amount between saturated and unsaturated geological materials because changes in heat capacity and thermal conductivity counteract each other. The geological heat flow literature contains numerous of studies examining the effect of changes in the ground surface temperature boundary condition (Ferguson and Woodbury, 2004, 2007; Taniguchi et al., 1999, 2005) and this should be considered more explicitly here. This is mentioned in passing on lines 24-25 of p. 7204 but warrant more discussion given the potential error this omission introduces to this study.

➔ As stated above, we agree that future work has to focus on capturing the physical processes taking place within the unsaturated zone. In the current model setup, the effect of dissipated heat from the public sewer systems and the district heating network was not accounted for. As most of these objects are mainly located in the unsaturated zone, a direct and instantaneous influence on thermal groundwater regimes was neglected. As local effects on the groundwater temperatures have to be expected, more sophisticated model setups should incorporate such objects to investigate the sensitivity on the system in future. However, currently the data are not available (network locations and especially depth).

➔ The following discussion should substantiate the assumptions made:

Only large buildings reach into the saturated zone, small and medium sized buildings, which cover most of the investigated area, typically only reach into depth of a several meters within the unsaturated zone.
Water budgets across the upper boundary (percolation of precipitation water) and through the unsaturated zone are small in comparison to southern and northwestern model boundaries (see table).
The "bulk" diffuse thermal input (saturated and unsaturated zone) from the southern model boundary (see table) is considered by the measurements of multilevel observation well IV.

Table: Water and heat budget for winter (summer)

	IN (m^3/d)	OUT (m^3/d)	IN (J/d)	OUT (J/d)
Dirichlet (southern model boundary)	2.3E03 (2.4E03)	5.0E01 (5.5E01)	2.9E10 (3.2E10)	9.9E10 (1.1E11)
Cauchy (River Rhine)	3.5E02 (1.5E00)	0.6E02 (1.8E03)	2.5E10 (9.6E11)	7.1E11 (2.0E08)
Cauchy (northwestern model boundary)	5.3E03 (4.0E03)	3.2E03 (4.4E03)	-	-
Wells	2.9E01 (1.1E03)	5.6E03 (4.3E03)	-	-
Dirichlet (thermal reinjection)	-	-	1.1E10 (3.5E09)	-
Dirichlet (thermal input buildings)	-	-	1.9E11 (6.2E09)	-
Areal groundwater/heat recharge	2E02 (1.0E03)	-	(3.7E10)	5.3E10
Areal basal heat flow	-	-	3.3E10 (3.3E10)	-

The temperature monitoring data strongly suggest advective-dominated heat transport. The relative importance of conduction and convection in the substrate can be assessed based on the Peclet number. Following the approach of Silliman et al. (1995), the dimensionless Peclet number can be determined by:

$$Pe = \beta \cdot v_a \cdot n \cdot l / D \,,$$

where the coefficient β can be determined by the ratios of the volumetric heat capacities of water (4184 Jm^{-3}°K^{-1}) and wet sediment (e.g., 2368 Jm^{-3}°K^{-1}; Lapham, 1989):

$$\beta = \frac{c_s \rho_s}{c_w \rho_w} = 0.57$$

The dimensionless coefficient β describes the distribution of thermal energy between water and soil (sediment) and ranges between 0.3 and 0.7 for natural conditions (De Marsily, 1986).

v_a are flow velocities ranging between 0.5 and 5 m/d (5.8E-06 and 5.8E-05 m/s; see manuscript)

n is the effective porosity and is in the order of 0.1

D is thermal diffusivity given by:

$$D = K_e / c_s \rho_s = 4.6E-07 m^2 s^{-1} \,,$$

where K_e is thermal conductivity (1$Jm^{-1}s^{-1}$°K^{-1}), c_s and ρ_s are volumetric heat capacity and density of the gravel deposits

l is the characteristic length and can be set to 1000m

This results in Peclet numbers in the order of 720 to 7200. Hence, the Peclet number is well above 1.0 and advection dominates.

➔ Concerning the proposed literature the references, if not already cited, can be integrated into the manuscript at the appropriate position):

Ferguson, G. and Woodbury, A. D.: Subsurface heat flow in an urban environment, Journal of Geophysical Research, 109(B2), 1–9, doi:10.1029/2003JB002715, 2004.

This reference is cited within the text concerning the heat island effect observed in urban environments. In contrary to the Basel case study, thermal regimes within shallow high permeable unconsolidated gravel deposits are not the issue. Furthermore, the approach is limited to solely synthetically models.

Ferguson, G. and Woodbury, A. D.: Urban heat island in the subsurface, Geophysical Research Letters, 34(23), doi:10.1029/2007GL032324, 2007.

Also this publication does not consider the role of advective heat transport within shallow high permeable unconsolidated gravel deposits.

Taniguchi, M., Shimada, J., Tanaka, T., Kayane, I., Sakura, Y., Shimano, Y., Dapaah- Siakwan, S. and Kawashima, S.: Disturbances of temperature-depth profiles due to surface climate change and subsurface water flow: 1. An effect of linear increase in surface temperature caused by global warming and urbanization in the Tokyo Metropolitan Area, Japan, Water Resources Research, 35(5), 1507, 1999.

This reference is cited within the text concerning the heat island effect observed in urban environments. The work estimates the vertical groundwater fluxes under the condition of surface warming caused by global warming and urbanization.

In the Basel model, these fluxes are considered by the upper atmospheric boundary conditions (precipitation and air temperature), the distribution of more or less sealed surfaces and the consideration of calibrated transfer rates (see manuscript and table). Calibration results indicate that the overall effect of the “bulk behavior” of the unsaturated zone is reproduced (see above). Furthermore, quantitatively areal groundwater recharge by percolating meteoric water is compared to other boundary conditions (areal groundwater inflow, river) small (see above). This also could be observed during the calibration process and the sensitivity of this parameter.

Taniguchi, M., Uemura, T. and Sakura, Y.: Effects of urbanization and groundwater flow on subsurface temperature in three megacities in Japan, 2(December 1992), 320–325, doi:10.1088/1742-2132/2/4/S04, 2005.

Also this publication does not consider the role of advective heat transport within shallow high permeable unconsolidated gravel deposits.

Other works have attempted to deal with the policy side of this work in a slightly different manner than those examined here. Some of these works have focused on the interplay between open loop heat pump systems (Fry, 2009) while others have taken a comprehensive view of subsurface heat sources (Bonte et al., 2011).

➔ The authors do not see the inconsistency between their and other works. All works bring up groundwater protection issues and discuss use conflicts.

➔ Concerning the proposed literature (in case the editor agrees the references can be integrated into the manuscript at the appropriate position):

Fry, V. a.: Lessons from London: regulation of open-loop ground source heat pumps in central London, Quarterly Journal of Engineering Geology and Hydrogeology, 42(3), 325–334, doi:10.1144/1470-9236/08-087, 2009.

The focus of this work is placed on the increasing number of systems being installed into the confined Chalk aquifer of central London. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Bonte, M., Stuyfzand, P. J., Hulsman, A. and Van Beelen, P.: Underground Thermal Energy Storage: Environmental Risks and Policy Developments in the Netherlands and European Union, Ecology and Society, 16(1), 22, 2011.

The authors do not see the inconsistency between their and this work.

There have been numerous other studies examining heat and groundwater flow resulting from withdrawal and subsequent injection related to thermal use of groundwater. Early theoretical studies focusing on analytical models (Gringarten and Sauty, 1975; Gringarten, 1978) might be of particular interest from a preliminary planning perspective. Later studies focusing producing calibrated models of production and injection (Bridger and Allen, 2010; Clarkson et al., 2009; Ferguson and Woodbury, 2005, 2006) suggest that producing meaningful models will take more data than was available to the researchers in the Basel area.

➔ Comment on statement "meaningful model":
The model has been developed for thermal groundwater management of the urban groundwater body of Basel. Calibration (which have been performed for different time periods and transient) shows that the model reproduces temperature distributions as well as seasonal temperature variations. Derived thermal retardation is comparable to other works in unconsolidated gravel aquifers (Labhart, 1988, Markle and Schincariol, 2007, Andrews and Anderson, 1979, Molson et al., 1992, Parr et al., 1983). Consequently the authors are confident to use the model as a planning tool and for studying thermal regimes within shallow high permeable unconsolidated gravel deposits.

➔ We further want to emphasize that in the Basel area groundwater is used by numerous municipal and industrial users. The application of analytical models would fail to evaluate the spatiotemporal transient impacts and would not allow considering seasonal influences.

➔ Concerning the proposed literature (in case the editor agrees the references can be integrated into the manuscript at the appropriate position):
Gringarten, A. C. and Sauty, J. P.: A Theoretical Study of Heat Extraction. From Aquifers With Uniform Regional Flow, Journal of Geophysical Research, 80(35), 4956–4962,1975.
Gringarten, A. C.: Reservoir lifetime and heat recovery factor in geothermal aquifers used for urban heating, Pure and Applied Geophysics PAGEOPH, 117(1-2), 297–308, 1978.
These works present analytical models for evaluating heat extraction, reservoir lifetime and heat recovery within uniform regional groundwater flow systems. Undoubtedly, this early work is of great value for estimating the influence of single heat extraction systems. However, these approaches do not account for the complexity of regional and local thermal and hydraulic complex boundary conditions as is the case in the Basel area.
Bridger, D. W. and Allen, D. M.: Heat transport simulations in a heterogeneous aquifer used for aquifer thermal energy storage (ATES), Canadian Geotechnical Journal, 47(1), 96–115, 2010.
Concerning the monitoring system described in Bridger and Allen (2010): They performed periodical measurement of vertical temperature distributions in production and monitoring wells and also state, that: *"It is important to note when interpreting the logs that fluid and thermal energy is able to move up and down in the well column" (p.101-102)*.
In Basel, monitoring of groundwater temperatures was performed continuously within multilevel observation wells and sensors within the saturated and unsaturated zone. Fluid and thermal fluxes within the monitoring wells can be excluded as sensors are separated by bentonite. Therefore a major source of errors when interpreting the data could be avoided. These monitoring systems are state-of-the-art devices for the presented investigations and the first time such high-resolution monitoring was performed in Switzerland.
Concerning model boundary conditions: Bridger and Allen (2010) state that *"Flow boundary conditions were invariant in time and assumed to reasonably represent typical or average conditions at the site" (p. 103).* The upper boundary was integrated as constant flux; thermal flux was neglected. Also lateral thermal fluxes and a geothermal gradient were neglected (p. 104).
Compared to the Basel case study, boundary conditions for the Agassiz aquifer model are quite simplified. The Basel case study takes several transient natural and anthropogenic boundary conditions into account.
Further Bridger and Allen (2010) *state (p. 111): "Heat transport in the Agassiz aquifer is controlled primarily by the influence of pumping and injection as well as regional groundwater flow and thermal dispersion associated with moving groundwater. Conductive transport is occurring in the aquifer, as would be expected, but is not the dominant transport process. As such, the properties and (or) conditions that influence convective*

heat transport, such as hydraulic gradient, aquifer permeability, pumping rate, and thermal dispersion, are the most critical to consider in modeling of the Agassiz aquifer and other aquifer systems where similar conditions occur".

These statements are in agreement with findings of the authors.

Bridger and Allen (2010) state *(p. 112): "However, given the detailed data needs and time required to construct and calibrate a heat transport model that incorporates heterogeneities, in most cases a simplified representation is sufficient to reproduce system behavior".*

This statement contradicts the statement of the reviewer about "meaningful models".

However, future model setups could also consider aquifer heterogeneity with respect to uncertainty (see below) as data sets for the consideration heterogeneity exist for the investigated area and have already been published (Epting et al., 2008b). However, such work would open a complete new field of investigations.

We propose to include the references at:

p. 7203, l. 19: Also Bridger and Allen (2010) who investigated the influence of aquifer heterogeneity (interbedded sands and gravels) on heat transport and storage, could demonstrate by simulation results that heat and (or) cold energy moved preferentially in discrete zones within the aquifer.

Clarkson, M. H., Birks, D., Younger, P. L., Carter, a. and Cone, S.: Groundwater cooling at the Royal Festival Hall, London, Quarterly Journal of Engineering Geology and Hydrogeology, 42(3), 335–346, doi:10.1144/1470-9236/08-080, 2009.

Case study conducted within a deep confined Chalk aquifer. Dimension of heat input is comparable to the Basel case study (incineration facility).

Ferguson, G. and Woodbury, A. D.: Thermal sustainability of groundwater-source cooling in Winnipeg, Manitoba, Canadian Geotechnical Journal, 1301, 1290–1301, doi:10.1139/T05-057, 2005.

Case study performed within the deep carbonate rock aquifer of Winnipeg. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Calibrating the model to situations involving well hydraulics is likely more important than the background case. It should also be noted that there is considerable uncertainty associated with the movement of groundwater and heat resulting from such projects (Bridger and Allen, 2010; Ferguson, 2007, 2012). Creation of a management plan based on more detailed models is probably unrealistic but uncertainty and upscaling issues should be considered here.

➔ The groundwater flow model and the distribution of horizontal and vertical hydraulic conductivities as well as river bed conductivities were calibrated and optimized several times during the different construction phases of a tunnel highway between 1994 and 2008 (Epting et al., 2008a, b). As the calibrated values resulted in very good to good modeling results (observed and calculated heads and water budgets) even at considerably different hydraulic (flood and drought events) and operational (massive construction site drainages) boundary conditions, the authors have confidence in the calibrated hydraulic parameters. Unlike hydraulic parameters, thermal parameters do not vary in magnitude. Therefore literature data were considered. Heat transfer rates in the unsaturated zone and in the river bed were inversely calibrated (see above).

➔ Concerning the proposed literature (in case the editor agrees the references can be integrated into the manuscript at the appropriate position):

Bridger, D. W. and Allen, D. M.: Heat transport simulations in a heterogeneous aquifer used for aquifer thermal energy storage (ATES), Canadian Geotechnical Journal, 47(1), 96–115, 2010.

See comment of literature above.

Ferguson, G. and Woodbury, A. D.: Urban heat island in the subsurface, Geophysical Research Letters, 34(23), doi:10.1029/2007GL032324, 2007.

This publication does not consider the role of advective heat transport within shallow high permeable unconsolidated gravel deposits.

Ferguson, G.: Characterizing uncertainty in groundwater-source heating and cooling projects in Manitoba, Canada, Energy, 37(1), 201–206, doi:10.1016/j.energy.2011.11.045, 2012.

Case study performed within the deep carbonate rock aquifer of Winnipeg. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

While there is a need to develop these sorts of plans, Basel appears to be a less than ideal area to develop the first comprehensive geothermal management scheme. Efforts to manage shallow subsurface thermal resources are scattered and there is little that have been done in terms of comprehensive planning (Haehnlein et al., 2010). However, there are other locations where there has been far more work done to support these developments. Cities such as London, UK (Ampofo et al., 2006; Clarkson et al., 2009; Fry, 2009; Gandy et al., 2010; Gropius, 2010; Headon et al., 2009), Winnipeg, Canada (Ferguson and Woodbury, 2004, 2005, 2006, 2007; Ferguson, 2012; Zhu et al., 2010) and Tokyo, Japan (Nakayama and Hashimoto, 2011; Nam and Ooka, 2010, 2011; Taniguchi et al., 1999, 2005) have been studied in detail and could provide much better opportunities to develop such a plan. A recent overview of the history of geothermal development of the Dogger aquifer in France (Lopez et al., 2010) may also be of interest. This aquifer has been supporting geothermal energy development for 40 years and may provide some interesting lessons. Development of a management plan based on a single study of Basel is could be possible. However, such a manuscript would need a more comprehensive treatment of the processes involved; uncertainties associated with development and a more thoughtful consideration of the experience in more extensively studied areas.

➔ The authors do not understand the argumentation of the reviewer concerning the selection of an ideal area for a comprehensive geothermal management scheme (see last paragraph of review)? Each urban location has specific natural (geology, hydrogeology and hydrology) and anthropogenic (groundwater use, urbanization…) settings and boundary conditions to be considered. Also the requirements for adaptation to climate change and mitigation measures as well as a sustainable development of urban groundwater resources are location specific. We present such a management approach for the Basel area. The concept and selected elements of the approach will be transferable to other urban areas. However, urban areas with different geological settings might require additional elements and especially a more sophisticated consideration of processes within the unsaturated zone or within deeper aquifer regions. We focus on thermal groundwater management within a shallow aquifer where advective flow processes dominate thermal groundwater flow regimes (see below). And finally we think that if this topic merits more attention in the development of sustainable solutions for urban hydrosystems, then we should force the dissemination of different approaches from different urban areas.

➔ Concerning uncertainties:
It is also unclear, which uncertainties the reviewer means, measurement errors, geological settings (bedrock surface), the consideration of heterogeneity of the gravel deposits (structure) or response uncertainties. However, we think that the role of uncertainty is an interesting research topic. In order to consider uncertainties, with respect of the used datasets, correctly and in a consistent way would open a complete new field of investigations. This would require to start with all possibilities that can be imagined and to exclude possibilities that can be rejected.
Concerning the uncertainty of monitoring data: To the best of our knowledge no study exists where a monitoring system (multilevel observation wells with temperature sensors in the saturated and unsaturated zone) was installed to study specific thermal processes. The monitoring systems have been designed in such a way that several major sources of errors could be avoided. Also the now available data allow interpreting measurement errors of temperature measurements in conventional observation wells.
Concerning the uncertainty of modeling: The flow model was calibrated and optimized according to for different time periods and transient. Hence, uncertainties concerning the flow field successively could be minimized (Epting et al., 2008a; Epting et al., 2008b).
Heat transport model: Thermal aquifer properties were taken from the literature but do not vary by orders of magnitude (compared to K-values)..

→ Concerning the proposed literature (in case the editor agrees the references, if not already cited, can be integrated into the manuscript at the appropriate position):

Haehnlein, S., Bayer, P. and Blum, P.: International legal status of the use of shallow geothermal energy, Renewable and Sustainable Energy Reviews, 14(9), 2611–2625, doi:10.1016/j.rser.2010.07.069, 2010.

This reference is cited within the text concerning international legal status.

Ampofo, F., Maidment, G. G. and Missenden, J. F.: Review of groundwater cooling systems in London, Applied Thermal Engineering, 26(17-18), 2055–2062, 2006.

This reference is cited within the text concerning more passive cooling solutions and was an impulse for the setup of the scenario caluculations.

Clarkson, M. H., Birks, D., Younger, P. L., Carter, a. and Cone, S.: Groundwater cooling at the Royal Festival Hall, London, Quarterly Journal of Engineering Geology and Hydrogeology, 42(3), 335–346, doi:10.1144/1470-9236/08-080, 2009.

Case study conducted within a deep confined Chalk aquifer.

Fry, V. a.: Lessons from London: regulation of open-loop ground source heat pumps in central London, Quarterly Journal of Engineering Geology and Hydrogeology, 42(3), 325–334, doi:10.1144/1470-9236/08-087, 2009.

The focus of this work is place on the increasing number of systems being installed into the confined Chalk aquifer of central London. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Gandy, C. J., Clarke, L., Banks, D. and Younger, P. L.: Predictive modelling of groundwater abstraction and artificial recharge of cooling water, Quarterly Journal of Engineering Geology and Hydrogeology, 43(3), 279–288, 2010.

Case study conducted within a sandstone aquifer.

Ferguson, G. and Woodbury, A. D.: Subsurface heat flow in an urban environment, Journal of Geophysical Research, 109(B2), 1–9, doi:10.1029/2003JB002715, 2004.

This reference is cited within the text concerning the heat island effect observed in urban environments. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Ferguson, G. and Woodbury, A. D.: Thermal sustainability of groundwater-source cooling in Winnipeg, Manitoba, Canadian Geotechnical Journal, 1301, 1290–1301, doi:10.1139/T05-057, 2005.

Case study performed within the deep carbonate rock aquifer of Winnipeg. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Ferguson, G. and Woodbury, A. D.: Observed thermal pollution and post-development simulations of low-temperature geothermal systems in Winnipeg, Canada, Hydrogeology Journal, 14(7), 1206–1215, doi:10.1007/s10040-006-0047-y, 2006.

Case study performed within the deep carbonate rock aquifer of Winnipeg. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Ferguson, G. and Woodbury, A. D.: Urban heat island in the subsurface, Geophysical Research Letters, 34(23), doi:10.1029/2007GL032324, 2007.

Also this publication does not consider the role of advective heat transport within shallow high permeable unconsolidated gravel deposits.

Ferguson, G.: Characterizing uncertainty in groundwater-source heating and cooling projects in Manitoba, Canada, Energy, 37(1), 201–206, doi:10.1016/j.energy.2011.11.045, 2012.

Case study performed within the deep carbonate rock aquifer of Winnipeg. In contrary to the Basel case study thermal regimes within shallow high permeable unconsolidated gravel deposits is not the issue.

Zhu, K., Blum, P., Ferguson, G., Balke, K.-D. and Bayer, P.: The geothermal potential of urban heat islands, Environmental Research Letters, 5(4), 044002, doi:10.1088/1748- 9326/5/4/044002, 2010.

This reference is cited within the text concerning the heat island effect observed in urban environments. However the work is limited to data interpretation and simple interpolation maps. These investigations do not consider the combined impact of different natural and anthropogenic impacts on urban thermal groundwater regimes.

Nakayama, T. and Hashimoto, S.: Analysis of the ability of water resources to reduce the urban heat island in the Tokyo megalopolis., Environmental Pollution, 159(8-9), 2164–73, 2011.

This reference is not relevant for the presented manuscript.

Nam, Y. and Ooka, R.: Numerical simulation of ground heat and water transfer for groundwater heat pump system based on real-scale experiment, Energy and Buildings, 42(1), 69–75, 2010.

This reference could be added to the manuscript. However, the work examines comparably simple setups of GWHP and does not consider the combined impact of different natural and anthropogenic impacts on urban thermal groundwater regimes.

Taniguchi, M., Shimada, J., Tanaka, T., Kayane, I., Sakura, Y., Shimano, Y., Dapaah- Siakwan, S. and Kawashima, S.: Disturbances of temperature-depth profiles due to surface climate change and subsurface water flow: 1. An effect of linear increase in surface temperature caused by global warming and urbanization in the Tokyo Metropolitan Area, Japan, Water Resources Research, 35(5), 1507, 1999.

This reference is cited within the text concerning the heat island effect observed in urban environments (see above).

Taniguchi, M., Uemura, T. and Sakura, Y.: Effects of urbanization and groundwater flow on subsurface temperature in three megacities in Japan, 2(December 1992), 320–325, doi:10.1088/1742-2132/2/4/S04, 2005.

Also this publication does not consider the role of advective heat transport within shallow high permeable unconsolidated gravel deposits.

Lopez, S., Hamm, V., Le, M., Schaper, L., Boissier, F., Cotiche, C. and Giuglaris, E.: Geothermics 40 years of Dogger aquifer management in Ile-de-France, Paris Basin, France, Geothermics, 39(4), 339–356, doi:10.1016/j.geothermics.2010.09.005, 2010.

Case study conducted within a Dogger aquifer; examining long time-scales (40a).

References

Lapham, W. W.: Use of temperature profiles beneath streams to determine rates of vertical groundwater flow and vertical hydraulic conductivity, U.S. Geol. Surv. Water Supply Pap. 2337, 35 pp., 1989.

Silliman, S. E., Ramirez, J. and McCabe, R. L.: GHB downflow through creek sediments using temperature time series: One-dimensional solution incorporating measured surface temperature: J. Hydrol., v. 167, p. 99-119, 1995.

Epting, J., Huggenberger, P., Rauber, M., 2008a. Integrated methods and scenario development for urban groundwater management and protection during tunnel road construction: a case study of urban hydrogeology in the city of Basel, Switzerland. Hydrogeology Journal 16, 575-591.

Epting, J., Huggenberger, P., Regli, C., Spoljaric, N., Kirchhofer, R., 2008b. Integrated Methods for Urban Groundwater Management Considering Subsurface Heterogeneity in: Cai, X., Jim Yeh, T.-C. (Eds.), Quantitative Information Fusion for Hydrological Sciences. Springer Series, pp. 183-218.