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EVALUATING AN 80 Hz TONAL NOISE FROM A HYDROPOWER PLANT

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Abstract
A pumped storage power plant produces significant noise such that adjacent areas were deemed uninhabitable for the local population. In recent years, the population in the area has increased, and the noise levels are now causing significant distress to the local population. The company operating the power plant and a citizens' initiative have both commissioned noise measurements. The measurements showed that the continuous pump noise was audible over many kilometers. The A-weighted sound-pressure level of 50 dBA at the next residential area underestimates the perceived noise, given the clear tonal nature in the low frequency range. Interviews of the exposed population, together with detailed "annoyance diaries" by a sample of the residents, proved their high level of annoyance. Their reported observations on distress and sleep disturbances coincide with the time course of the pumping operation. The pumping noise leads to annoyance in a large area, and to considerable nuisance in a smaller one. For the most exposed homes, long-term exposure might be considered a health hazard due to stress and disturbances in sleep quality. Therefore, the operator committed to developing a technical noise control plan. This case shows that a scientific approach within a complex environmental noise problem can foster an agreement about noise protection measures. However, this can only be successful if all involved parties participate in the process. Pilot studies are underway to test the impact of damping material layers on the pipes, the housing of the pipes, and the kind of air vessel solutions between the pumps and the pipes. Int J Occup Med Environ Health. 2019;32(3):401–11

Key words:
tonal noise, hydropower plant, noise annoyance, public health evaluation, community-based prevention, low frequency noise

INTRODUCTION

Shortly after the Second World War the first storage power plants were constructed in the mountainous area of Upper Carinthia. This work was heralded as a hallmark of progress and reconstruction after the war. Electricity from Alpine hydropower was coined the "White Gold of the Alps" [1] and school classes from all over the country visited the remote areas to witness the success story. The enterprise that constructed and ran the power plants was then owned by the regional government. Infrastructure objects originally built to support the construction and maintenance of the power plant, such as cable cars to the new lakes in the mountains, were opened to tourists, thus providing business opportunities for the local tourism industry.

Another larger power plant was planned and finally built in the 1970s. Then, already detailed surveys were performed concerning noise pollution in the residential area near the new power plant, and some houses were identified as being exposed to excessive levels of noise [2–4]. Therefore, the owners were offered financial compensation and were forced to leave their original homes. Some of these houses were later sold by the electric power company to new owners, who were required to sign a contract acknowledging that these houses were not intended for permanent residence.

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Since that time the village next to the power plant has grown and new houses have been built close to the area that was previously deemed unfit for permanent residence. The power plant was sold to a national enterprise that did not invest as much to support the local tourism infrastructure. The construction of another artificial lake higher up in the mountains after 2010 caused much unrest. Heavy duty traffic on the way up the mountain passed through the crowded centers of local villages and a new road was required to reach the new construction site. Thereafter, the old cable car was no longer needed. Consequently, the construction work in the mountains and the subsequent rearrangements impacted heavily on alpine tourism.

These recent developments have likely contributed to an increasing opposition among the local population against the emissions of the power plant. When it was felt the management did not react to complaints in a timely and considerate manner, a citizen's initiative was formed and local politicians were lobbied for action. In March 2016 the affair culminated in an open council where one author was asked to provide expert input. It soon became evident that the lack of mutual trust complicated the dispute. It was agreed that the electric power company would engage an engineer to measure noise and vibrations. The citizen's initiative employed another engineer to ascertain the validity of the results. The authors were engaged by both parties to evaluate the results of the measurements from a health perspective.

When they entered the debate, distrust between the parties was widespread. The citizens widely believed that the power plant had not only increased the pumping duration but that noise levels had also grown in intensity and were higher than originally approved in the 1970s. The managers argued that noise levels had remained practically unchanged and it was only the sensitivity of the people that had increased. The authors, however, got the impression that the managers were willing to search for technical amendments although they needed a confirmation for their own stakeholders that these measures were necessary for medical reasons.

Current health-based guideline values for noise are mostly based on studies on transport noise [5–7], while health effects of noise from other specific sources with a particular sound characteristic are scarce.

MATERIAL AND METHODS

Noise data

The authors were able to get access to the old noise data from the 1970s. Measurements were taken along the pipes that connected the power station at the bottom of the valley and the lake situated over 1000 m above. When water is pumped up through the pipes, the pumps induce a fluctuation in the water column with a frequency of ca. 80 Hz. This 80 Hz sound is emitted over the full length of the pipes and is heard in a wide area throughout the valley and also on the opposite mountain slopes. Measurements were also taken in the vicinity of the power plant and helped to define a "no residence" area based on a maximally allowable A-weighted sound level of 50 dB (night-time outdoor noise, limit value for urban residential areas in Austria [8]).

Another set of measurements were undertaken more recently. At some of the same points, as in the 1970s, in the "no residence" area noise measurements were performed again in 2008 as well as in 2015.

The company provided data on the annual duration of the pumping operation and a detailed time series of the pumping operation in 2016. The engineer mandated by the company performed measurements at 4 points in the residential areas. These measurements were carried out upstream and downstream of the plant over approximately a week when during the nights with low wind speed the pumps and turbines were run at predefined operational states. Meteorological data were also monitored at a central site. The first measurement point (MP1) was a house near the "no residence" area (a distance to the pipes: 1057 m).

The claim of an increase in noise intensity was tested by comparing historical data with new acoustic data. The claim of the increasing noise frequency was tested by regressing the annual pumping operation times over time.

The engineer mandated by the citizens' initiative performed measurements at a time blinded to the company at the same measurement point (MP1). That house was deemed representative of the most affected area although it was not the most exposed, being partly protected behind a small hill, which was not the case for other neighboring houses. The second measurement point (MP2) was located in the same village as MP1, i.e., upstream or west of the power plant, but further away (1971 m to the pipes) and on the other side of the river, with the nearby river dominating the sound-scape. The third measurement point (MP3) was situated in the center of the same village (a distance to the pipes: 2026 m), near the main road that dominated the sound-scape. The fourth and the fifth measurement points (MP4 and MP5, respectively) were situated in another village, downstream or east of the power plant, and further away than MP1. The fourth measurement point (MP4) (a distance to the pipes: 1658 m) was in the center of the village, and MP5 (a distance to the pipes: 1543 m) in a more quiet residential area.

Originally, either the pumps were operated, when a surplus of electricity had to be stored (typically during the night and at weekends), or the turbines, when there was a need for additional energy. In more recent times, the national electrical grid has been in need for more sophisticated stabilization measures. Thus, the power plant has to accept or release very precise amounts of wattage, and the demand changes quickly and frequently. Since the pumps can only be operated at 1 maximal power state, the exact wattage is achieved by operating 1 or 2 pumps and 1 or 2 turbines (at varying states) in parallel. It was proposed during the public hearings that some specific parallel operation state might increase the noise emissions due to a short circulation of water between the pumps and the turbines.

The noise levels reported by the 2 engineers at MP1 were compared and found to be in the same range for similar operational stages of the power station. Since the data collected by the engineer hired by the company could be linked to detailed operational stages and were available for 5 measurement points, these data were then further investigated. In spite of similar operational stages, the noise levels varied at a given measurement point. This was due to additional chance noise sources and also to changing meteorological conditions.

To estimate the average noise levels for the defined operational states, a linear regression per measurement point was performed with the sound level (transformed to units of 20 μPa, afterwards again expressed as dB) as the dependent variable. Separate analyses were performed for the sound level in decibels equivalent to the total A-weighted sound energy measured over a stated period of time ($L_{A,eq}$), the A-weighted sound pressure level that was exceeded in 95% of the measurement time ($L_{A,95}$), and the sound pressure level at the 80 Hz band. The independent variables were a dummy for day-evening-night (with night being the reference period), and the number of pumps and turbines in operation, either alone or in combination. At first, different combinations of pumps and turbines were included in the models as separate dummies to investigate the "short circulation" hypothesis. However, the number of pumps and turbines affected the noise levels independently of each other and, therefore, the final model could be simplified. Meteorological data (wind speed and direction) were also originally included in the analysis but were then left out because they did not significantly alter the other coefficients. This is likely due to the fact that low wind situations were chosen for the measurement period. Alternatively, a regression analysis over all measurement points was performed that included the measurement points as dummy variables, or the distance from the power plant and an interaction term of wind direction and location relative to the source.

For demonstration purposes, only night-time levels were calculated separately. Also, for ease of presentation, "pumping" was coded 0–2 depending on the number of pumps being operated, and "turbine operation" was coded 0–4 accordingly. Night-time levels were calculated and shown for either 2 pumps or 2 turbines in (full) operation.

Citizens' reports

The citizens were invited to keep a diary and note when they observed the pumping noise and how they perceived it. Many citizens also provided written statements on how they felt about the situation, and their most common frustrations. Furthermore, several citizens (24 households) were interviewed during an extended visit to the area in May 2016.

The diary action was scheduled to take place in 2016, but most citizens only started recording at the end of April. The diaries were completed with varying degrees of accuracy. Some people made a note every day, even though they only said there was no noise from the pump or that they were not at home so they could not comment on that day, whereas others only recorded when disturbed. Some specified the time of the day when the problem occurred, whereas others were less precise and wrote only the date and possibly "in the evening" or "at night." Therefore, in the first step, the descriptive entries were transformed in a semi-quantitative scale by respondent and day. If it was explicitly stated that no pump noise could be heard, the value "0" was assigned to it. If no entry was made or it was declared that the respondent had not been at home during that day, the field remained empty (missing value). If pump noise was reported, "1" was entered for this day. If it was additionally reported that the noise was "very loud" or "disturbing" (except if it was explicitly stated that it only disturbed outdoors and especially while walking near the pumping station), or if health effects were reported (e.g., "was awakened by that noise or prevented from falling asleep"), the value "2" was assigned instead.

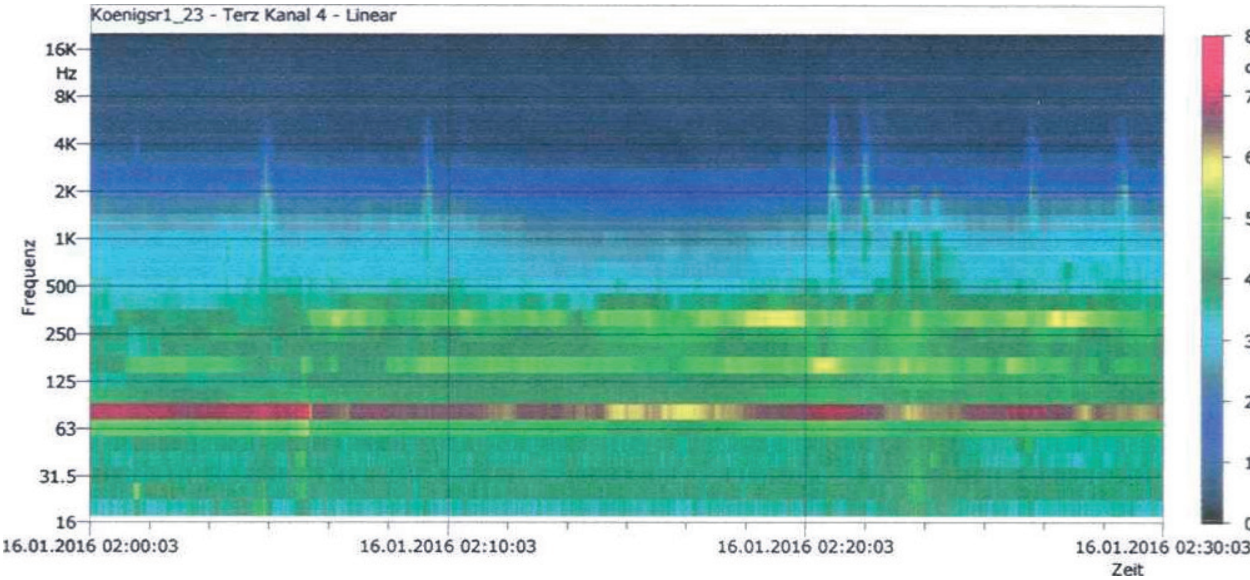
In the second step, the daily codes per person were correlated with each other person's codes. When it was ascertained that there was a sufficient correlation between the observations, especially between the observers living down- and upstream (east and west) of the power plant, all observations of each day were averaged. In the third step, that time series of averaged observations was compared to the company's records. These records reported the operation of each pump and each turbine every 15 min (96 data pts/day, taking the value of 0–2 for the pumps or 0–4 for the turbines). So, the average pump intensity and the average turbine intensity could be calculated for each day. The "daily average observations" were then correlated with the "average pump intensity" and the "average turbine intensity" separately.

RESULTS

Noise measurements in the residential areas

The results of the sound measurements of the 2 engineers at MP1 were comparable. The engineer hired by the citizens' initiative also performed frequency-selective measurements and provided color-coded presentations of the findings. These served well to demonstrate to the interested citizens that what they heard could also be measured (Figure 1). The initiative's engineer reported an $L_{A,eq}$ of about 50 dB(A) at night during the pumping operation. The same level was reported by the other engineer. As can be seen from Figure 1, the third-octave band varied in intensity. So, while the average levels reported by the company's engineer were around 65 dB, the peaks reached ≥ 70 dB.

Tables 1–3 report the sound levels at 5 measurement points. At some points, some parameters (e.g., constant and turbine for the 80 Hz band) were not significantly different from 0. Some of these coefficients even became negative in the linear regression model. Since the logarithm of negative values cannot be calculated, the sound pressure levels for these parameters were set to "(0)".



X-axis – time; Y-axis – frequency.
Color coding in unweighted dB.

Figure 1. An example of the color-coded frequency-specific sound-pressure levels at the first measurement point (MP1) during pumping operations at night, based on measurements on site in Carinthia (2016)

Additionally, the authors present the calculated night-time levels for either 2 pumps or 2 turbines (Tables 1–3). As the results of the linear regression analysis (coefficient ± standard error), the night-time noise without the pumping operation is represented by the constant factor. The coefficients must be added to the constant to provide the noise level during the day or during the pumping operation. In spite of the distance to some of the MPs and the other noise sources, the impact of the operation of the pumps was clearly detectable in the 80 Hz band. Dis-

Table 1. Sound pressure levels in the 80 Hz band at 5 measurement points (MP) at night by operation status at the power plant, based on measurements on site in Carinthia (2016)

Model fit/ operation status	Sound pressure levels in the 80 Hz band [dB]				
	MP1	MP2	MP3	MP4	MP5
Adjusted R^2	0.53	0.38	0.17	0.61	0.49
Night-time without operation	(0)	(0)	40.2	47.8	43.3
Operation of 1 pump	**65.3**	**60.1**	**44.8**	**57.5**	**48.6**
Operation of 1 turbine	53.5	50.7	(0)	(0)	(0)
Operation of 2 pumps	68.1	62.8	48.5	60.8	52.2
Operation of 2 turbines	51.3	49.9	39.2	47	30.8

Bolded – $p < 0.001$.
* Calculated from the coefficients provided by the applied model.

Table 2. The A-weighted sound pressure level that was exceeded in 95% of the measurement time ($L_{A,95}$) at 5 measurement points (MP) at night by operation status at the power plant, based on measurements on site in Carinthia (2016)

Model fit/ operation status	$L_{A,95}$ [dB]				
	MP1	MP2	MP3	MP4	MP5
Adjusted R^2	0.52	0.45	0.54	0.15	0.40
Night-time without operation	**37.1**	47.3	37.6	(0)	34.8
Operation of 1 pump	**40.2**	(0)	28.3	**43.0**	**33.9**
Operation of 1 turbine	**34.2**	**39.8**	**32.6**	37.6	(0)
Operation of 2 pumps	44.2	46.8	38.5	45.9	39.0
Operation of 2 turbines	40.2	48.6	39.7	40.0	33.8

Bolded – $p < 0.001$.
* Calculated from the coefficients provided by the applied model.

Table 3. The sound level in decibels equivalent to the total A-weighted sound energy measured over a stated period of time (L_{Aeq}) at 5 measurement points (MP) at night by operation status at the power plant, based on measurements on site in Carinthia (2016)

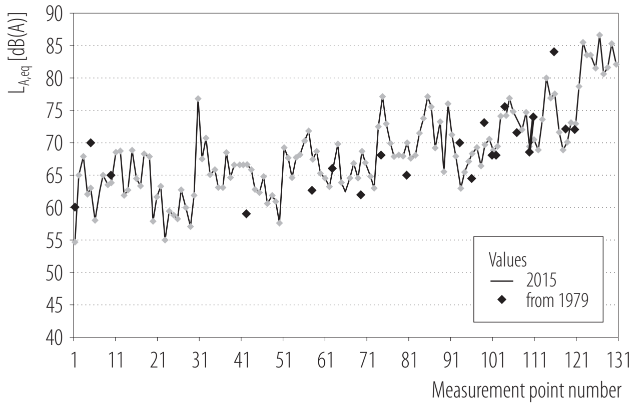
Model fit/ operation status	L_{Aeq} [dB]				
	MP1	MP2	MP3	MP4	MP5
Adjusted R^2	0.03	0.14	0.46	0.24	0.07
Night-time without operation	47.4	49.6	47.0	46.4	46.7
Operation of 1 pump	**45.6**	38.4	**43.2**	46.3	39.3
Operation of 1 turbine	(0)	39.5	27.6	47.6	(0)
Operation of 2 pumps	51.0	50.2	49.7	51.1	48.1
Operation of 2 turbines	47.3	50.4	47.1	52.0	44.8

Bolded – $p < 0.05$.
* Calculated from the coefficients provided by the applied model.

tance to the pipes was a significant predictor ($p < 0.001$) of 80 Hz levels. Pumping also significantly increased the $L_{A,95}$ in all MPs but the 2 were either exposed to river or traffic noise. Interestingly, also the turbine operation increased the $L_{A,95}$ at some points although the turbines did not contribute to the disturbing tonal sound and did not affect $L_{A,eq}$.
Even the $L_{A,eq}$ was significantly affected by the pumping operation in some instances (MP1: $p = 0.007$, MP3: $p = 0.032$). The combined operation of the pumps and the turbines did not lead consistently to a greater increase in the noise levels. Therefore, presenting the impact of the pumps and the turbines separately was appropriate. There were no special operation settings (e.g., the pump plus the turbine at a certain watt production) that caused more pronounced noise signals. At MP1, during the pumping operation, and even during the night, the 80 Hz band displayed a sound pressure level of 65 (1 pump) to 68 dB (2 pumps). The $L_{A,eq}$ reached about 50dB (A) at night, no matter whether 1 or 2 pumps were operated.
The intensity of the pumping noise did not generally differ from historical data. Figure 2 depicts the measurements

along the pipes (A-weighted levels in 1–2 m distance from the pipes) during the pumping operation. At an abandoned farmhouse in the "no residence" zone, measurements were taken in 1979 and 2015 although it is not clear if exactly the same place was chosen in both instances. The $L_{A,95}$ was 67 dB(A) in 1979 and 63 dB(A) in 2015 during the pumping operation. During the pumping operation, the continuous sound from the pumps was so loud that $L_{A,eq}$ and $L_{A,95}$ were practically identical.

There were a few locations where an increase in the noise levels may have occurred. The engineer in charge of the power plant reported about a very frequently used foot path leading about 100 m above the valley floor, along the sunny slopes of the mountain. This path crosses the pipes by a small bridge. Originally, that bridge had a hand-rail made of wood, which was at some point replaced by a metal handrail. The new metal vibrated with the pipes and became a relevant source of additional local noise. This has been partly fixed but the noise at the crossing continues to attract significant complaints from local residents and holiday tourists.



Measurement points numbers start at the mountain lake – the highest numbers represent points near the pumping station in the valley.

Figure 2. Noise levels at measurement points 1 through 141 near the pipes (1–2 m distance), based on measurements on site in Carinthia (1979, 2015)

Citizens' reports

The citizens' diaries were organized by the citizens' initiative. Due to the misunderstanding between the initiative and the power company, dates of the diaries and the pumping operation overlapped only partially. Analyzing the citizens' diaries was a complex task due to the nature of collected data. Citizens only rarely documented when they did not hear the pumps. Many also failed to note when they were not at home so that hearing the pumps was not an issue (not at risk time period). They seldom provided exact times but would usually note observations like: "last night I had poor sleep and woke up several times and the pumps were always very loud," or: "4 p.m.: finally the pump noise has ceased. But during the last few hours it was very troublesome."

In total 19 citizens kept a diary. Of these 15 reported a sufficient number of overlapping days to run pairwise comparisons. These would yield 105 pairs with correlation coefficients, but 9 pairs still did not have enough overlapping days. For the other 96 pairs, Spearman's rank-order correlations were calculated. Only 12 correlation coefficients were (slightly) negative, all the others were positive, with 44 pairs with a $\varrho > 0.5$ and significantly different from 0. A complete correlation was not to be expected because citizens reported from different places that might have been affected differently, depending on wind direction and likely also on different periods of the same day. The averages for each day from all the 19 reports were calculated.

The daily operation of the pumps was only weakly correlated with the daily operation of the turbines ($r = 0.18$, $p = 0.04$). The reported annoyance correlated significantly ($r = 0.61$, $p < 0.001$) with the pumping operation, but not with the turbine operation ($r = 0.11$, $p = 0.21$). The reported annoyance thus does reflect well the actual operational state.

The initiative collected a total of 445 signatures of complainants. Most of them live in the villages near the power plant but a few signatures were also obtained from holiday guests or visitors. Some of the signatories also pro-

vided very vivid descriptions of their annoyance. The community upstream (west) of the pumping station consists of 17 villages and has approximately 2300 inhabitants in total. Overall, > 12% of the inhabitants signed the protest note, ranging from none in the most distant village to 100% in the nearest. In the community east and downstream of the station, 83 of approximately 1000 inhabitants signed the protest note, and in the next community further down still 51 of approximately 2500. Some more signatures were provided by people living further away and visiting the valley mostly for recreational purposes, including 3 regular holiday guests from Vienna.
Interviews were conducted with approximately 40 inhabitants living on both sides and in varying distances from the pumping station. Since usually whole families were interviewed instead of single persons, it is not possible to provide an exact number of people, but 24 households were visited. Access to the people had been arranged by the citizens' initiative. Nevertheless, the reports made by the people sounded fairly plausible and certainly not exaggerated. The people reported their annoyance and eventually (those living nearest to the pumping station) also sleep disturbances. Many explained that they were mostly annoyed when the pumping nose interfered with recreational outdoor activities, especially as many walking paths cross the pipes or lead along the artificial lake at the bottom of the pipes.
None of the interviewees claimed specific diseases caused by the noise. However, some reported chronic diseases and suggested these might increase their vulnerability to noise. Some people very impressively described psychosocial effects, like anger and perceived helplessness.

Operation times

Data on the annual operation of the pumps was available for the years 2005–2015. In 2013 the lowest number of operating hours was recorded, most likely due to the construction work on the new lake. The highest number of operation hours was recorded in 2015 and a linear regression of pumping hours over the years displayed a positive, though insignificantly increasing, trend.
The detailed reporting for 2016 was not fully comparable with the annual data from 2005–2015. However, it seems that in 2016 even higher pumping rates were encountered. At least 1 pump was operated in 48% of all the observation periods. During nights (68%) and at weekends (74%) the percentages were even higher. For 2 pumps, the respective percentages were 22% and 34%. Overall, 2 pumps were operated in 15% of the time. Since the actual operational state was documented every 15 min, frequent on/off changes in the pumping operation were evident.
The local plant manager observed that complaints by telephone were mostly raised at weekends when the on/off changes of the pumping operation were the most frequent.

DISCUSSION

The annoyance reported in the diaries and by signatories is plausible. Although the diaries were incomplete and the intensity of annoyance was difficult to quantify, the time courses of the reported annoyance and the pumping operation were highly correlated with each other during approximately half a year when the comparisons were possible to make. This indicates the validity of the diary data in spite of all the shortcomings. Through many private talks to citizens in the neighboring villages, a realistic picture of the complaints was established. People did not attribute severe acute diseases to the pumping noise, but described their annoyance, a feeling of helplessness, frustration and anger. Some did report subjective symptoms that could plausibly be explained by repeated sleep disturbance (such as headache and sleepiness), but usually acknowledged that these symptoms were not specific and could have many causes.
Noise emissions during the pumping operation have remained mostly constant over the years. However, in more recent years (2013) there was a substantial drop in the annual operation time because of construction work. The

reemergence of frequent pumping noise afterwards certainly contributed to an increased awareness and discomfort of the citizens.

Pumping operations are most frequent during nights and at weekends, when neighbors are more often at home and expect a quiet, restorative environment. Pumping is always more frequent in the times of reduced energy demand, but in more recent years the requirements of the electrical grid have become more complex, thus necessitating more frequent on/off switches. It is highly plausible that the changing pumping operation are more noticeable than continuous operation. The complex requirements also called for the parallel operation of pumps and turbines. This, by itself, did not lead to significantly louder operational states. However, the combined operation both enabled and necessitated an overall increase in pumping duration.

The sound of the pumps and the water column in the pipes is especially disturbing due to its single-tone character. The sound is heard even many kilometers away when the A-weighted sound pressure level is no longer affected. Its distinct characteristics make it stand out clearly and initiate the feelings of annoyance.

Annoyance, or even severe annoyance, was not just reported but was also plausible based on the measured noise levels. Administrative legal rules make it mandatory that not just annoyance but also health risks are stipulated to enforce mitigation measures from enterprises with an existing operation license. Thus, a medical expert judgment was required that answered the question of health risks.

An increasing number of epidemiological studies provide evidence of adverse health effects of environmental noise, even at rather moderate levels [e.g., 9,10]. These studies are mostly based on traffic noise, and in particular road traffic noise [11]. This case describes a different type of noise.

Non-auditory health effects of noise are generally believed to be mediated either through the "annoyance – stress reaction – stress hormones" or the "sleep disturbance – chronic exhaustion" pathway [12]. However, nocturnal noise can also lead to stress responses [13]. Annoyance is a complex psychological process that involves a conscious assessment of a situation. An exposure must be perceived as outstanding and must be distinguished from the "normal" background in order to trigger such a conscious assessment. A single frequency noise, as in the case of the pumping operation, has exactly such features.

Sleep disturbance, in turn, is more strongly triggered through (unexpected) peak noise events [14,15]. However, even a continuous sound, when loud and disturbing enough, can cause difficulties in falling asleep. The unpredictable on-off nature of the pumping noise could still lead to disturbances of sleep or changes in sleeping phases. So, on the one hand, the specific noise from the pumping operation might be considered more harmful than traffic noise of the same magnitude (because of the tonal character); on the other hand, it could be considered less harmful (because of the absence of peak events). In the absence of reliable epidemiological data concerning that special type of noise, and considering the overwhelming evidence of very high annoyance, it is argued that the pumping noise is at least as harmful as transport noise of similar loudness.

A-weighted noise levels greatly underestimate loud low frequency noise because, at higher sound pressure levels, the isophones are much less frequency dependent than that at 20 phone that is reflected by the A-filter [16]. Even the dB values for the third-octave band underestimate the true loudness of the one outstanding single frequency. However, even for 60–70 dB at 80 Hz, as documented at MP1, a C-weighted sound pressure level would much better represent the actual perceived loudness.

Many standards suggest penalties for "tonal" noise or noise with one outstanding frequency. The definitions of "tonal noise" differ between standards and are usually either based on sensory perception or on third-octave data. Both definitions are rather unsatisfactory and, therefore, penalties are usually discouraged [17]. In the case of a truly single-frequency noise, some penalty is, nevertheless, warranted.

Epidemiological studies indicate adverse health effects of road traffic noise > 50–55 dB(A) outdoors at night. In the neighborhood closest to the power plant, the A-weighted sound-pressure level at night during the pumping operation was documented as ≥ 50 dB(A). The C-filter would reflect the actual loudness much better and would provide > 10 dB higher levels. Thus, even without a penalty for tonal noise, it was concluded that noise levels are reached that pose a health risk for the nearest neighbors in the case of long-term exposure.

CONCLUSIONS

The medical conclusion of a health risk prompted the operators to seek technical mitigation measures. Pilot studies are underway to test the impact of damping material layers on the pipes, the housing of the pipes, and the kind of air vessel solutions between the pumps and the pipes.

A very detailed evaluation of the situation, the combination of technical expertise from different engineers acting independently from each other, and a comprehensive analysis of all data taking into account and documenting the various complaints from many citizens proved to be a viable way in mediating a very problematic conflict. Ultimately, the operators were glad to see a proposed way forward. The communication between the operators and the neighbors improved again since they could agree on common goals and also on a detailed plan for improvement.

The medical evaluation, based on public health concepts, was key to that success. Nevertheless, this example showed again that public health decisions must often be taken in the absence of good scientific data and must fit the tight requirements of legal definitions such as "health risk."

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